Classification of Informal Settlements Based on their Susceptibility to Climate Change

Case study of Ahmedabad, India

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Applied Research Paper I Spring 2018
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1. Introduction

1.1 Impact of Climate Change on India

The changing climate impacts society and ecosystems in a broad variety of ways. For example, climate change can alter rainfall, influence crop yields, affect human health, cause changes to forests and other ecosystems. Climate-related impacts are occurring across the world and impacts many sectors of the economy (US EPA, 2017) The Global Climate Risk Index (2016) ranks India in 10th place. The index analyses to what extent countries have been affected by the impact of extreme weather-related events (storms, floods, heat waves etc.) between 1995 and 2014 (Kreft et al., 2013). This predicts the country's vulnerability and susceptibility to the impacts of climate change in the future.

Climate change in India can be seen in the perspective of a three-part transition: a demographic transition that will see India's population stabilizing at about 1.6 billion in the 2060s; a simultaneous rural to urban transition, which will add nearly 500 million people to the country's urban settlements over this period; and a simultaneous environmental transition – brown (water, sanitation and environmental health), grey (air and water pollution) and green (climate change). Multiple sub-regionally nuanced strategies will be needed to respond to the climate crisis, drawing on considerable local experience of coping with uncertainty and with systems far from equilibrium. (Revi, 2008)

1.2 Impact of Climate Change on Indian Cities

Unlike most of the rest of the world, South Asia has been marked by low levels of urbanization despite being one of the most urbanized pre-colonial regions of the eighteenth century. Only 31.16% of India's population lived in urban areas in 2011, but given its 1.1 billion-plus population, its urban population still exceeds that of Japan, the European Union and most other regions of the world except for the United States and China. Over the next 40 years, India will experience one of the most dramatic settlement transitions in history, as its urban population grows from about 300 million to more than 700 million. By 2025, an estimated 70 Indian cities are expected to have a population exceeding one million. Three mega-urban regions: Mumbai–Pune (50 million), the national capital region of Delhi (more than 30 million) and Kolkata (20 million) will be among the largest urban concentrations in the world. By midcentury, India could

have both the largest urban and rural populations of the time. This will have an important bearing on global climate vulnerability and the potential for mitigation and adaptation. (Revi, 2008)

Most Indian communities and institutions have a history of coping with uncertainty and extreme events with great equanimity (Revi, 2008). However, the current pressure on resources, high population densities and ongoing rapid economic, technological and slower social changes imply that a mix of institutional, market- and community-led mitigation and adaptation interventions will be necessary if future losses are to be within tolerable bounds. The poor and vulnerable, who suffer the most in extreme events, should be the priority.

1.3 Definition of Slums

In their transition to urban areas, a large number of rural migrants make their homes in slums. Unfortunately, there are problems in identifying slums through absolute measures. The first is that standards differ across the world so what is considered to be a slum by poor people in one place may be regarded as perfectly acceptable accommodation by much poorer people in another. What is considered to be unfit clearly varies from place to place.

The second problem is that many low-income settlements in the world are not homogenous. While some settlements lack every kind of service and infrastructure, others are partially serviced. Those settlements without water may be classified as slums but what about those settlements with provision but where inhabitants cannot afford to pay for it? Diversity is inherent in many older shanty towns where some plots contain substantial houses with several stories and others flimsy shacks.

The third issue is that the word 'slum' is not just an absolute but is also a relative concept. It cannot be defined safely in any universally acceptable way. Nor is the concept stable across time because what is consider to be a 'slum' changes. For example, in cities where the general quality of housing gradually improves, areas that do not change become 'slums' because of their relative neglect. (Gilbert, 2007)

Terms such as slum, shanty, squatter settlement, informal housing and low-income community are now used somewhat interchangeably by agencies and authorities in countries. The terms used in India include *chawls* (Ahmedabad,

Mumbai), *katras/jhuggi-jhompdi* colonies (Delhi), *bustee* (Kolkata), *zopadpattis* (Maharashtra, Gujarat), *murikiwadas* (Andhra Pradesh) etc. (Ministry of Housing and Urban Poverty Alleviation, National Buildings Organization, 2011)

The definition of what constitutes a slum, like that which constitutes an urban area more generally, differs by country, state and even city (Nolan, 2015). The following are some standard definitions:

UN-HABITAT defines a slum household as a group of individuals living under the same roof in an urban area who lack one or more of the following:

1. Durable housing of a permanent nature that protects against extreme climate conditions.
2. Sufficient living space which means not more than three people sharing the same room.
3. Easy access to safe water in sufficient amounts at an affordable price.
4. Access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people.
5. Security of tenure that prevents forced evictions.

Not all slums are homogeneous and not all slum dwellers suffer from the same degree of deprivation. The degree of deprivation depends on how many of the five conditions that define slums are prevalent within a slum household. (Housing & slum upgrading – UN-Habitat, 2017)

The national government of India has adopted the following definition of a slum in Census of India, 2001:

- All specified areas in a town or city notified as 'Slum' by State/Local Government and UT Administration under any Act including a 'Slum Act'.
- All areas recognized as 'Slum' by State/Local Government. Housing and Slum Boards, which may have not been formally notified as slum under any Act.
- A compact area of at least 300 populations or about 60-70 households of poorly built congested tenements, in unhygienic environment usually with inadequate infrastructure and lacking in proper sanitary and drinking water facilities.
- Residential areas where dwellings are unfit for human habitation by reasons of dilapidation, overcrowding, faulty arrangements and design of such buildings, narrowness or faulty arrangement of street, lack of ventilation, light, or sanitation facilities or any combination of these factors which are detrimental to the safety and health.

For the Census, slums have been categorized and defined as of the following three types: notified slums, recognized slums and identified slums. Notified slums are those areas in a town or city notified as 'Slum' by State, Union territory (UT) Administration or Local Government under any Act including a 'Slum Act'. Recognized slums are areas recognized as 'Slum' by State, UT Administration or Local Government, Housing and Slum Boards, which may have not been

formally notified as slum under any act. Finally, identified slums are compact areas of at least 300 population or about 60-70 households of poorly built congested tenements, in unhygienic environment usually with inadequate infrastructure and lacking in proper sanitary and drinking water facilities. (Ministry of Housing and Urban Poverty Alleviation, National Buildings Organization, 2011). Although the exact measures for what constitutes a slum is highly debatable, The Challenge of Slums - Global Report on Human Settlements 2003 summaries attributes of a slum by reviewing definitions used by national and local governments, statistical offices, institutions involved in slum issues and public perception. (UN-Habitat, 2004)

Attributes	Description
Lack of basic services	Lack of access to improved sanitation facilities and improved water source, supplemented sometimes, by the absence of waste collection systems, electricity supply, surfaced roads and footpaths, street lighting and storm water drainage.
Sub-standard Dwelling	High number of substandard housing structures often built with non-permanent materials unsuitable for housing, given local conditions of location and climate, e.g. earthen floors, mud-and-wattle walls, thatched roofs, etc. – often in violation of housing norms and standards locally applicable.
Over-crowding and High Density	Very low space per person, high occupancy rate, co-habitation by different families and a large number of single-room units. Often five and more persons share a one-room unit for cooking, sleeping and living.
Unhealthy/Hazardous Conditions	Unhealthy living conditions due to lack of basic services - open sewers, lack of pathways, uncontrolled dumping of waste, polluted environment, etc. Houses may be built on hazardous lands, unsuitable for settlement, such as floodplains, drains, river beds, garbage dumps, and on areas prone to landslide.
Insecure Tenure/Informal Settlements	Lack of formal document entitling the occupant to inhabit the land or structure - illegality of living; informal or unplanned settlements cropping up on public lands or lands reserved for non-residential purposes, especially for conservation.
Poverty and Exclusion	Income poverty is sometimes considered a characteristic of slum-dwellers, but not always. Slum conditions are physical and due to statutory and regulatory factors that create barriers to human and social development.
Minimum Settlement Size	Many slum definitions also require some minimum settlement size. The municipal slum definition of Kolkata requires a minimum of 700 square meters to be occupied by huts. Census of India 2001 requires at least 300 people or 60-70 households living in a settlement cluster.

Table 01: Attributes and description (UN-Habitat, 2004)

The table below compares the attributes that are mentioned within three standard definitions used to identify slums. (Nolan, 2015)

	Legality	Density	Housing	Water	Sanitation
Census of India	X	X	X	X	X
National Family and Health Survey (NFHS)		X	X	X	X
UN		X	X	X	X

Table 02: Attributes included within standard definitions (Nolan, 2015)

1.4 Vulnerability of Slums to Climate Change

Due to the concentration of population, urban areas are particularly vulnerable to climate change. Within cities, climate change will disproportionately affect the poor people who constitute between a quarter and half of Indian cites. The slum dwellers, squatters, migrants, people living in informal settlements, which are generally situated in vulnerable areas (river beds, flood plains, hill slopes), will be directly affected. (Impact of Climate change on Urban Areas in India, 2017)

Ironically, but not surprisingly, the urban residents most vulnerable to climate change are the poor slum and squatter settlement dwellers and those who suffer from the multiple insecurities that poor governance, the lack of serious investment in the commons and a strong nexus between the political class, real estate developers and public agencies bring to cities. Through a long process of loss accumulation, they are multiply challenged by even small events that impact their livelihoods, income, property, assets and sometimes their lives. Because of systematic exclusion from the formal economy of the city – basic services and entitlements and the impossibly high entry barrier into legal land and housing markets – most poor people live in hazardous sites and are exposed to multiple environmental health risks via poor sanitation and water supply, little or no drainage and solid waste services, air and water pollution and the threat of being evicted. (Revi, 2008)

1.5 Key Climate Stressors

The four key climate stressors are (a) heat waves; (b) flooding and inundation; (c) water scarcity; and (d) increased climate change-related incidence of water and vector borne diseases. These factors were identified by the Global Resilience Partnership through research and field work.

a) **Heat waves:** Global warming will be felt more in cities because of the urban heat island effect that makes cities 2 to 6^{o}C warmer than their surrounding countryside because of the modification of the land surface and waste heat produced by high-energy use. Heat waves, that can kill hundreds of people, may become more frequent and intense. (Impact of Climate change on Urban Areas in India, 2017)

Heat vulnerability can be conceptualized as a function of interacting biophysical and socioeconomic determinants that can be broken down into heat hazard probability as well as factors associated with population exposure, susceptibility, and adaptive capacity.

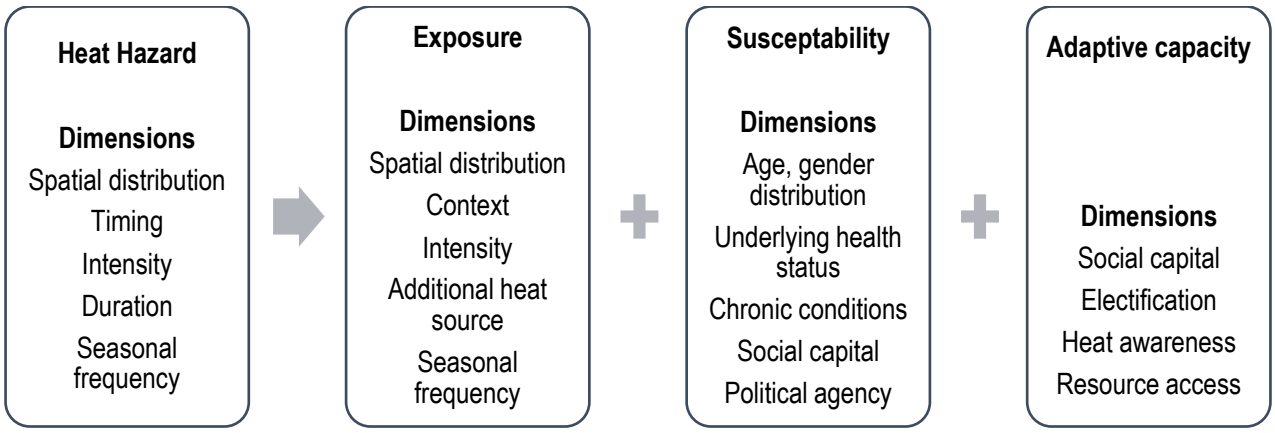


Fig. 01: Attributes of heat hazards (Tran et al., 2013)

Exposure refers to the degree to which the host (e.g., a person, household, neighborhood, or city) is physically exposed to the hazard. Exposure can be affected by hazard factors (e.g., magnitude, persistence, distribution), amplifying factors (e.g., buildings that retain heat, urban heat islands), and protective factors (e.g., air conditioning, exposure avoidance). Susceptibility (or sensitivity) relates to the impact of exposure, and is influenced by host characteristics such as demographics (e.g., age, socioeconomic status, social capital) and underlying health status (e.g., obesity,

comorbid condition). Adaptive capacity is the ability to make protective changes to reduce health burdens, in response to actual or expected hazards. In the context of heat as a health hazard, these factors can be influenced and driven by climate variability, urban form, occupational conditions, infrastructure, and interventions that might include warnings, surveillance, and education. (Tran et al., 2013)

b) **Flooding and inundation:** Changes in precipitation patterns and water cycle will increase the already existing problems of flooding and water inundation in low lying areas and areas with poor drainage and sewage infrastructure. In megacities large populations survive on limited natural resources, and poor households do not have any access to these already scarce resources. This problem is even more evident in case of non-notified slums because these slums are unregistered and illegal and therefore cannot be formally integrated with the development plans of the urban system.

Mitigation strategies in urban areas indicate patterns of disconnect between different sectors in the city. Public funds are more likely to be used for large scale risk reduction policies that benefit members of the formal economic sector and global clients. For problem areas and communities like slums, state institutions only take partial responsibility of immediate relief after an event. (Chatterjee, 2010).

c) **Water scarcity:** Changes in precipitation patterns and water cycle will increase the already existing problems of water supply and quality in urban areas, especially in big cities in drier areas. Drought has two typical first-order impacts on cities: drinking water shortages and increases in food and fuel prices. It also has a number of important second-order impacts: depressed demand for urban produced secondary goods and services because of depressed agricultural demand; and increasing seasonal and distress migration from rural areas to cities. (Revi, 2008)

d) **Diseases:** Warmer and/or wetter period of breeding will provide ideal conditions for expansion of mosquito-borne diseases as puddles (in which malaria carrying mosquitoes breed) are created either by excessive rainfall or by droughts in rivers. Lack of sanitation and potable water will increase contaminated water and food-borne diseases like cholera, typhoid, diarrhea, hepatitis, and gastroenteritis. Warmer cities will also induce an increase in respiratory diseases due to pollution whose effects are reinforced by higher temperatures. (Revi, 2008).

Effects of weather and climate on health (Martine & Marshall, & 2007)	
Heat stress	• Deaths from cardio respiratory disease increase with high and low temperatures • Heat related illness and death due to heat wave
Air pollution related mortality and morbidity	• Weather affects air pollutant concentrations • Weather affects distribution, seasonality and production of aeroallergens
Health impacts of weather disasters	• Floods landslides and windstorms cause direct effects (death and injuries) and indirect effects (infectious disease, loss of food supplies etc.)
Mosquito borne diseases	• Higher temperatures reduce the development time of pathogens in vectors and increase potential transmission to humans.
Water/food borne diseases	• Survival of important bacterial pathogens is related to temperature. • Extreme rainfall can affect the transport of disease organisms into the water supply particularly in areas with inadequate sanitation infrastructure.

Table 03: Summary of known effects of weather and climate on health (Martine & Marshall, & 2007).

Poor people may suffer more as they have lesser possibilities to adapt. As stated by UNFPA, 'poor areas that lack health and other services, combined with crowded living conditions, poor water supply and inadequate sanitation, are ideal for spreading respiratory and intestinal conditions, and for breeding mosquitoes and other vectors of tropical diseases such as malaria, dengue, typhoid and yellow fevers. Changes in temperature and precipitation can spread disease in previously unaffected areas and encourage it in areas already affected'. (Martine & Marshall, & 2007). Subsequently, this will impact morbidity, mortality and productivity.

2. Research Context and Research Question

The purpose of this study is to assess the relative vulnerability of slums within the city of Ahmedabad, India to four key climate stressors. These are (a) Heat waves; (b) flooding and inundation; (c) water scarcity; and (d) increased climate change-related incidence of water and vector borne diseases. This research derived proxy measures from remote sensing data and publicly available socio-economic data to assess relative vulnerability within 16 settlements. The analysis was conducted on two levels 1) vulnerability with respect to the relative position of the slum within the city 2) characteristics within the settlement that contribute to vulnerability to climate change.

The use of remote sensing data to assess vulnerability of slums to climate change is largely untested. While the potential for using such remote measures to identify particularly vulnerability communities is significant, little is known about the limits of current capacities and the techniques that might be used to create such measures. This research, then, is primarily a test of potential uses of remote sensing and their integration with demographic data to identify vulnerabilities, to identify their strengths and weaknesses as an assessment tool.

This research builds on existing climate change intervention work conducted by Mahila Housing SEWA Trust (MHT). MHT is an autonomous organization promoted by the Self Employed Women's Association (SEWA) in 1994 with the vision to realize the right to shelter and dignity for all. Its programs address basic civic and housing infrastructure needs, including water, sanitation, drainage, solid waste management, roads, electricity/energy, low-income housing and secured land tenure. (Mahila Housing Sewa Trust, 2018).

The Project, '*The Women's action towards managing health impacts of climate change affecting urban poor In south Asia Project (2016-2018)'* was realized by MHT, to build the resilience capacity of women from slum communities in seven cities of South Asia, to take the lead in action against the four key climate risks. (Mahila Housing Sewa Trust, 2017). This research assesses vulnerability in 16 slums that were intervened in the city of Ahmedabad, as part of this project and provides recommendations.

The main research question of this study is: How can remote sensing data be utilized to assess susceptibility to climate change in slums?

The sub questions in this study are

- How can the vulnerability to the four key climate stressors be assessed and ranked?
- What policy and urban design recommendations can be provided to build resilience?

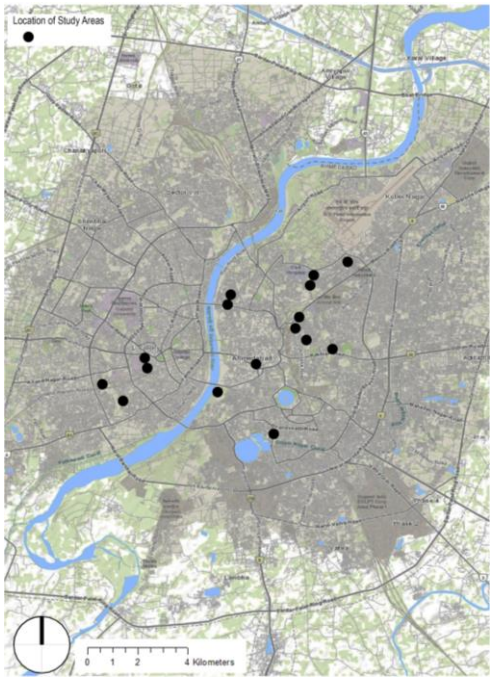


Fig. 02: Location of the 16 study areas within the city of Ahmedabad (Source: Base map-ESRI, Locations- MTH). (Enlarged map in Appendix 01)

3. Methodology

Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites. (NOAA,2018). While first uses of remote sensing data for land use classification were confined to large-scale cartographic and agricultural studies, the 1970s saw the initial use of satellite imagery in urban research. Today, remote sensing systems and image analysis techniques have developed to an extent where it can contribute significantly to the mapping, characterization, measurement, and thus explanation of form, morphology, and evolution of large-scale urban landscapes. (Kit, Lüdeke & Reckien, 2012)

3.1 Remote Sensing and the Study of Slums

The successful launch of Ikonos-2 on 24 September 1999 heralded a new era in the application of Remote sensing data in the study of urban areas. The increased availability of high and very-high-resolution imagery produced by sensors such as Ikonos, QuickBird, WorldView (very-high-resolution sensors (VHR) have spatial resolutions of the

PAN band of 1 m and below, while high-resolution (HR) sensors have between 1 and 5 m spatial resolutions) have provided a new and rich data repository for urban research in general and for slum-related research in particular, as it allows for a more detailed spatial analysis (Dare & Fraser, 2001). While the first sensors were launched by countries in the Global North, the number of launches of sensors by countries in the Global South has increased (such as NigeriaSat), decreasing the cost of data and increasing availability. (Kuffer, Pfeffer & Sliuzas , 2016).

In many cities, slums are a major part of the urban housing stock and an important part of the urban economy. It is important to realize that "slums disappear not through being removed, but by being transformed" (Cobbett, 2013) However, accurate information on slums, specifically their scale, location, extent, boundaries, populations, buildings and enterprises is lacking. Conventional data sources, such as maps, statistics, or even geodata are usually obsolete, not available, not as accurate as needed or do not hold the information needed. (Taubenböck, & Kraff, 2014). Remote sensing can play a key role in analyzing "space−time dynamics", such as monitoring densification and expansion processes or assisting in the implementation of slum improvement policies. Furthermore, it allows linking the urban morphology with socioeconomic parameters. The range of its application is presented in the table below. (Kuffer, Pfeffer & Sliuzas, 2016).

Domain	Application area
Economy	• Economic condition
Environment	• Environmental depravation • Environmental protection • Hazards & vulnerability
Governance/Planning	• Land management • Planning interventions and growth models • Urban governance
Social	• Health • Humanitarian • Quality of life • Crime

Table 04: Application domains of remote sensing based information on the morphology and temporal dynamics of slums (Kuffer, Pfeffer & Sliuzas, 2016).

New methodologies and tools as well as techniques and policies are required to monitor urban growth and alteration across the megacity and to forecast areas of risk – all within shorter time frames and at a larger scale than previously accepted (Herold, Goldstein, & Clarke, 2003). This will support a more proactive and sustainable urban planning and land management (UN, 2002). The availability of remote sensing data has created spatiotemporally continuous and politically less biased sources of data.

3.2 Limitations

Accurate detection and classification of informal settlements using remote sensing data pose real challenges to researchers and decision-makers alike. Unlike agricultural land or other natural vegetation types, urban structures lack unique and easily distinguishable spectral signatures (Kit, Lüdeke & Reckien, 2012). The second major challenge is that slum conditions can take various forms and, therefore, no universal model of slums existed. This is due to differences in slum-development processes, their age and thus developmental stages (infancy, consolidation, maturity), geographical location and context (e.g., central versus peri-urban). Hence, the diversity of urban slums and geographic contexts requires methodological adjustments. (Cobbett, 2013)

4. Literature Review

4.1 Ahmedabad and its informal settlements

The city of Ahmedabad is located in the western state of Gujarat, in India. It is 53 meters (174 ft.) above sea level and covers an area of 464 km^2. The city is bifurcated by the Sabarmati River into the eastern and western regions. The terrain is mostly flat with some hillocks in the northern parts of the city (*Thaltej-Jodhpur Tekra*). It falls under seismic zone 3, in a scale of 2 to 5 (in order of increasing vulnerability to earthquakes). (Bhatt, 2003)

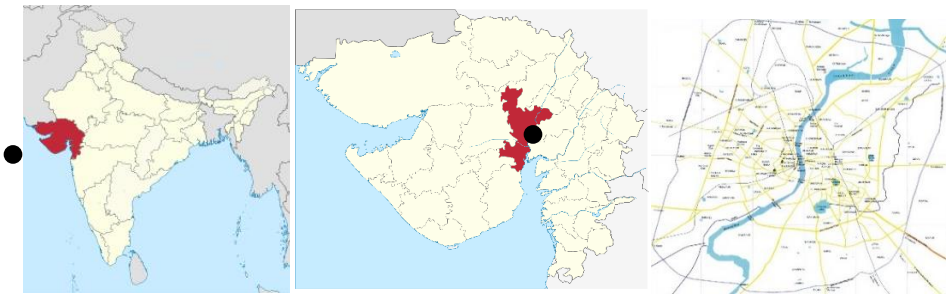


Fig. 03: Location of Ahmedabad within the country and state.

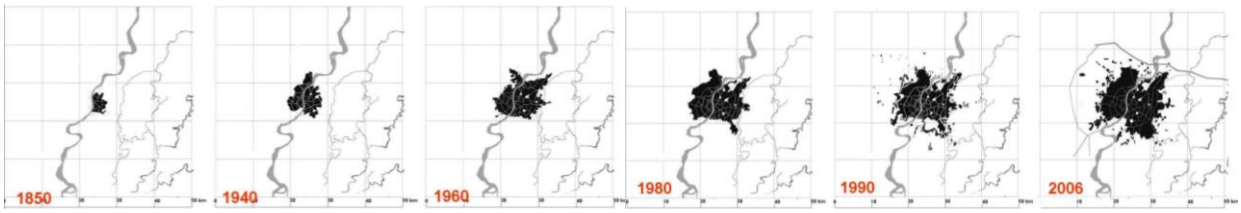


Fig. 04: Growth of the city between 1850 and 2006 (HCP, 2015).

Ahmedabad has a hot, semi-arid climate with marginally less rain than required for a tropical savanna climate. There are three main seasons: summer, monsoon and winter. Aside from the monsoon season, the climate is extremely dry. The weather is hot from March to June; the average summer maximum is 43 °C (109 °F), and the average minimum is 24 °C (75 °F). From November to February, the average maximum temperature is 30 °C (86 °F), the average minimum is 13 °C (55 °F), and the climate is extremely dry. Cold northerly winds are responsible for a mild chill in January. The southwest monsoon brings a humid climate from mid-June to mid-September. The average annual rainfall is about 800 mm(31 in), but infrequent heavy torrential rains cause local rivers to flood and it is not uncommon for droughts to occur when the monsoon does not extend as far west as usual. (Bhatt, 2003)

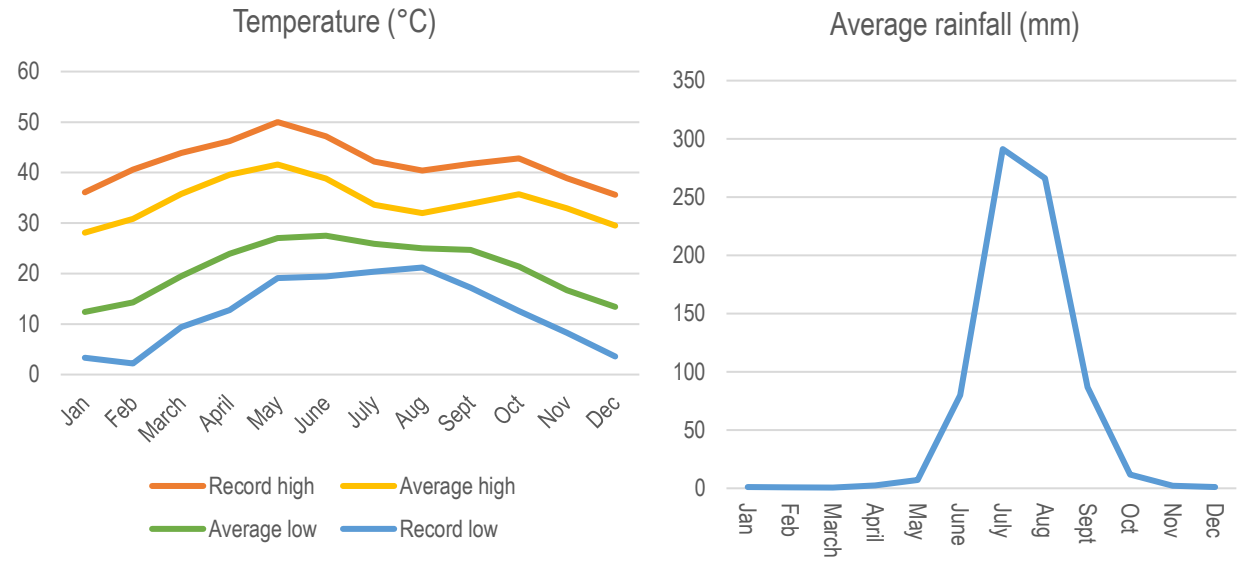


Fig. 05: Climate data for Ahmedabad (1981–2010) (NOAA, 2018)

4.1.1 The City and its Slums

Ahmedabad is the largest city and former capital of Gujarat. With a population of more than 5.8 million and an extended population of 6.3 million. It has been one of the chief drivers of Gujarat's economic progress. The city has achieved

significant progress since the 1990s. At the state level, the urban poverty rate declined from 28% in 1993-94 to 10% in 2011-12. Trade unions, such as the Self-employed Women's Association, founded in Ahmedabad in 1972, have played a key role in organizing and empowering informal workers. There has also been a dramatic decline in the share of Ahmedabad's population recorded as living in slum settlements, from 25.6% in 1991 to 4.5% in 2011, and an improvement in the well-being of slum dwellers (Bhatkal, Avis, & Nicolai, 2015).

Approximation of number of slum dwellers in Ahmedabad has been a challenge. The definition of slums has varied across agencies that have conducted surveys. For example, the government survey includes only notified slums whereas other surveys include the homeless population. The Ahmedabad municipal area boundary has also grown over the years as surrounding areas were annexed and incorporated into the city.

Year	Population living in slums	Source
1991	0.46 million	AMC
2001	0.44 million	Census of India
2001	0.91 million	AMC
2002	~3.5 million	AMC
2006	~1.8 million	Nirmal Gujarat Sanitation Program
2009	~1.31 million	AMC
2011	0.80 million	Census of India
2012	3.4 million (34,13,080)	AMC Health Department

Table. 05: Estimation of slum population in Ahmedabad by different agencies across the years. (Killemsetty, 2013), (UMC, 2103) and (Mahadevia, Desai & Vyas, 2014).

Despite the discrepancy on the exact numbers, a general consensus in the literature is that quality of life for slum dwellers has improved over the years.

4.1.2 Planning Interventions

Major planning interventions are currently designed, planned and implemented in two ways: through Town Planning Schemes (TPS) and through urban projects.

The TPS mechanism is a planning tool, which allows for a detailed reconstitution of the land in the area, with land allocation for various uses as well as raising funds for infrastructure. Under this mechanism, private land plots are readjusted to suit infrastructure and area is reserved for public use (such as parks and schools). Land owners are compensated for the land they loose and property values increase once the scheme is implemented. TPS also allocates areas for low income housing but since the plan takes several years to design and implement, it does not meet the housing demand.

The second approach is through urban projects like the Sabarmati Riverfront Development project. These are planned and implemented in existing parts of the city. They are treated as discrete projects, and planning is often done in the project area without paying attention to adjacent areas and links of the “project area” to the rest of the city and its dynamics. A Special Purpose Vehicle (SPV) or board in created to oversee the project under the purview of AMC. (Mahadevia, Desai & Vyas, 2014)

4.2 Climate Change and the City of Ahmedabad

Studies conducted by the Indian Council of Agricultural Research (ICAR) show that the state of Gujarat has been ranked 2nd among Indian states facing severe environmental threats. As many as 14 districts of the state have been included in the "very high" category under vulnerability indices relating to climate change. (Chauhan, 2016). Owing to its geo-climatic, geological, and physical features, the state of Gujarat is vulnerable to all types of major natural disasters, including drought, floods, cyclones, earthquakes, and tsunamis, and other disasters (such as fire, industrial, chemical, and biological disasters) (NIDM, 2014). The state has over 1,600 km of coastline and settlements, both urban and rural, which could be impacted by sea level rise in terms of inundation of low lying coastal areas, sea water ingress into the coastal groundwater aquifers and loss of ecologically fragile and important mangroves and wet lands. The incidences of storm surges and cyclones could bring heavy economic and structural losses to communities besides making the entire area vulnerable to water resources particularly for drinking and agricultural purposes. (Government

of Gujarat I Climate Change Department, 2014). Although the city of Ahmedabad may not directly be impacted by some of these vulnerabilities, such as sea level rise, under extreme events people are likely to migrate to the city as climate refugees.

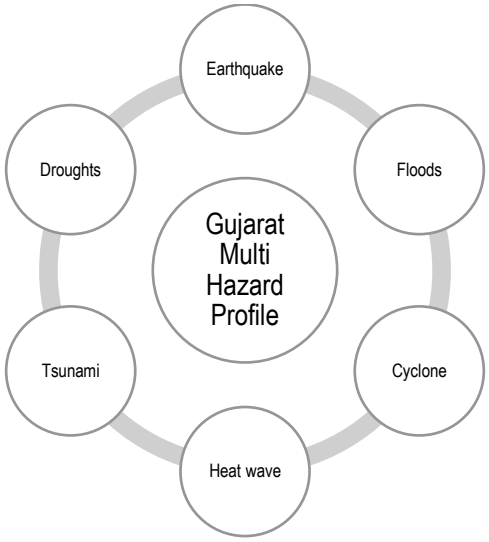


Fig.06: Multi hazard profile of Gujarat

4.2.1 Vulnerability to Heat Waves

The global as well as regional temperature modeling results show a rise in the range of 1.5 to 2.5°C. Historically, this area has recorded a high number of heat waves (Government of Gujarat I Climate Change Department, 2014).

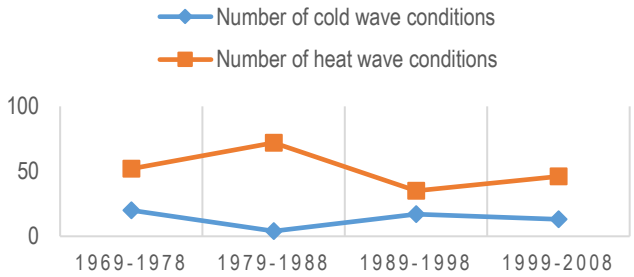


Fig.07: Decadal frequency of heat wave and cold wave (Ray, Mohanty & Chincholikar, 2009).

In May 2010, temperatures in Ahmedabad reached 46.8°C (more than 116°F). Nearly 3000 deaths were linked to this heat wave. (AMC, 2017). Events of similar magnitude are likely to occur in the future. The city is further likely to be impacted by urban heat island effect and lose of vegetation.

4.2.2 Vulnerability to Flooding and Inundation

The city is susceptible to three types of flooding: pluvial flooding due to river overflow, localized flooding due to lack of proper drainage or storm water infrastructure and flash floods due to rapid transformation of land cover. Between 1969 and 2008, the city witnessed 181 extreme rainfall events. (Ray, Mohanty & Chincholikar, 2009).

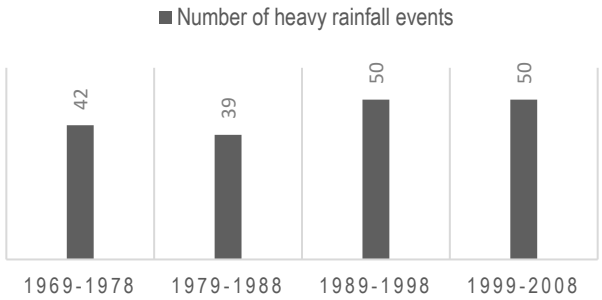


Fig.08: Decadal frequency of heavy rainfall events (Ray, Mohanty & Chincholikar, 2009).

Ahmedabad is located on the flat alluvial plains of the Sabarmati River, and is prone to flooding from river overflow or pluvial flooding. (NIDM, 2014). The Sabarmati riverfront development project that is currently under construction aims to control this but it is uncertain whether projections on climate change informed its structural design.

Fig.09: Baba Lavalavinagar (slum) before the river front construction in 2000 and after construction in 2017. (Source: Google Earth)

Overall, summer monsoon rainfall is projected to increase by 3 to 7 % in the 2030's with respect to the 1970's. Projections of extreme rainfall events do not show any particular trend for the frequency of rainy days. However, intensity of rainy days is projected to increase. (Government of Gujarat I Climate Change Department, 2014). The increase in rainfall intensity will further aggravate impact due to localized flooding and flash floods.

4.2.3 Vulnerability to Water Scarcity

Gujarat is one of the most chronic drought prone states of India - large parts of North Gujarat and Saurashtra have no sources of alternate irrigation and are increasingly vulnerable to drought from groundwater exploitation (NIDM, 2014). Between 1875 and 2004, Gujarat region faced 27 droughts of which 11 were considered severe and 16 moderate. (Kaur, 2004). Today, 90% of the water provided by the municipality of Ahmedabad comes from surface sources (Central Ground Water Board, 2011). Projections in increase in periods and severity of droughts in the region, coupled with population growth will have a large impact on future demand and supply of water.

4.2.4 Vulnerability to Vector Borne Deceases

Weather conditions determine transmission of vector borne deceases to a significant extent. Climate Change will modify the dispersal, reproduction, maturation and survival rate of vector species and consequently alter disease transmission. Heavy rainfall and resultant puddles provide breeding conditions for mosquitoes. Currently, malaria, dengue fever, and chikungunya are prevalent in the state and these fevers are transmitted through mosquitoes. Dengue cases have increased since 2008 and sporadic cases of chikungunya have also been reported in the city.

Conversely, scabies too was prevalent in the State till 1994. The condition is aggravated by water scarcity, and is a communicable disease that spreads rapidly in drought prone regions. As future projections indicate decrease in water availability it could further increase the case of scabies. (Government of Gujarat I Climate Change Department, 2014).

4.2.5 Gaps to be Addressed

No comprehensive study on the impact of climate change on the city of Ahmedabad has been undertaken. Future predictions and trends, for this paper, have been extrapolated based on historical data, and a High resolution regional climate model (PRECIS) projection for the state of Gujarat as presented in the State Action Plan on Climate Change. To introduce effective interventions and policies, it is vital an assessment is made at the city scale incorporating the impact of urban heal island effect and socio-economic vulnerabilities. It is also important to forecast the growth of the city incorporating climate refugees.

4.2.6 Policy Responses at the State Level

In the year 2008, The Government of India adopted a National Action Plan on Climate Change (NAPCC). In 2009, the central government urged states to create and adopt a state level action plan consistent with the strategies outlined in the national plan. In 2009, the state of Gujarat created a new Department of Climate Change to oversee initiatives. As parts of its efforts, the department adopted a State Action Plan on Climate Change in 2014. Till now, the departments' main priority has been towards mitigation efforts and not adaption. In 2015, the government adopted the 'Gujarat Solar Power Plan,' and in 2016 the' Wind Power Policy'. Both of these policies were put in place to encourage adoption of renewable energy. (Climate Change Department, Government of Gujarat, 2018)

Although, one of its state objectives is 'Empowering communities for participatory and decentralized action on Climate Change.', (Climate Change Department, Government of Gujarat, 2018), the department has made no concrete efforts to realize it. In the following section baseline condition for each of these key stressors was assessed. The predictions above implicate how conditions are likely to worsen in the future. Key predictions are summarized in the table below

Heat wave	Increase in number of incidents
Flooding and inundation	Increase in number of incidents
Water scarcity	Increase in severity of droughts, increase in urban water scarcity
Vector borne deceases	Increase in number of cases

Table.09: Future predictions

5. Assessment of Baseline Condition- At the City Level

5.1 Heat Wave

Ahmedabad witnessed an additional 1,350 deaths during the heat wave of May 19-25, 2010, which included an extreme heat wave condition for four days. This represents 43% increase in deaths compared with the corresponding period in 2009. The Indian Meteorology Department (IMD) defines heat wave as one where the temperature is 5 to 6 °C higher than normal daily historical maximum temperature (over a 30-year period). (AMC, 2017)

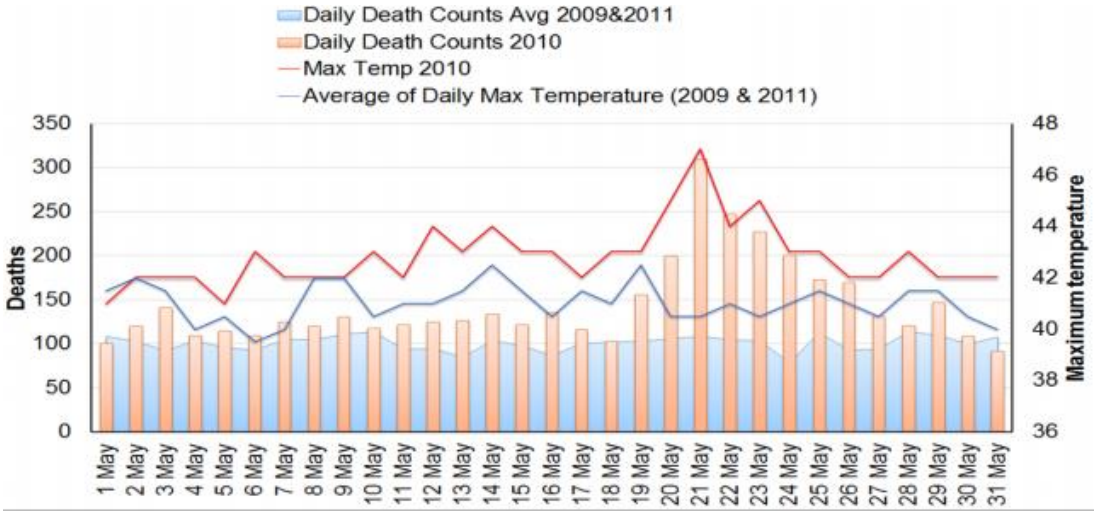


Fig. 10: Temperature and all-cause mortality correlation during the 2010 heat wave in Ahmedabad as compared to 2009. On May 21st of 2010, there were over 300 deaths compared to 100 in 2009 and 2011. (AMC, 2017)

5.1.1 Exposure

Slum dwellers are especially susceptible to heat exposure both in terms of duration of exposure and lack of accessibility to key resources. Slum communities have fewer adaptation options since they often lack control over their home and work environments, with limited access to, and inability to afford, reliable electricity and cooling. (Kaur, 2017) A survey of 1650 slum dwellers across 6 slums in Ahmedabad shows that 89.7% of those who are employed work outdoors during the summer. Of this, 15.2% work directly under the sun. (Tran, 2012) Studies show that often slum dwellers are employed within these low pay but physically strenuous jobs. (TNN, 2017)

Acclimatization to heat is an example of physiological adaptation and often the impact of heat waves are underestimated, particularly in warm regions. With repeated heat exposures, human's defense mechanism undergoes progressive changes for internal thermal stability. The degree of exposure to combined load of work and heat, however, reflects differently on the thermoregulatory mechanism. This brings the limitation that individuals may not have the ability to be exposed at widely different hot environments. (Nag & Nag, 2009)

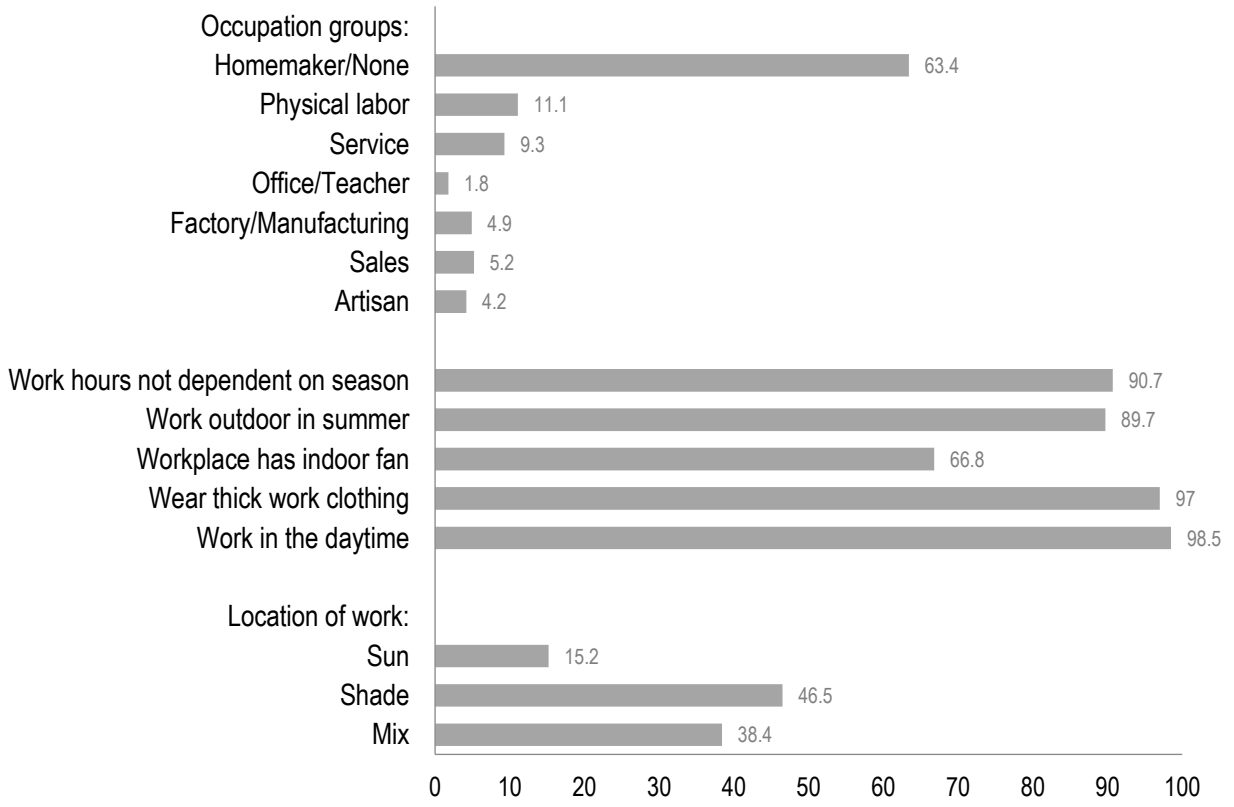


Fig. 11: Degree of exposure to heat in slums. N=1650 (Tran, 2012). Data collected through the study*, 'Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad'*

Slum residents are likely to have higher exposure to extreme heat because their homes are constructed of heat-trapping materials such as tin or tarp roofs, and their communities lack trees and shade (Kaur, 2017). On the other hand, 63.4% of the respondents are homemakers, children or the elderly population who stay at home. Condition of the surrounding built environment makes significant impact on their response to extreme heat events. Within the household, indoor cooking creates additional heat which further increases exposure. 89.3% of the households cook indoors twice a day. (Tran, 2012) Although 96.5 % of the households leave the windows open, this may not be a sufficient exhaust system.

On the other hand, only 24 households had no windows (8%). 41.3% of households with windows frequently kept them open, 42.8% of the households opened their windows depending on the weather outside and 15.9% rarely opened their windows. (Tran, 2012)

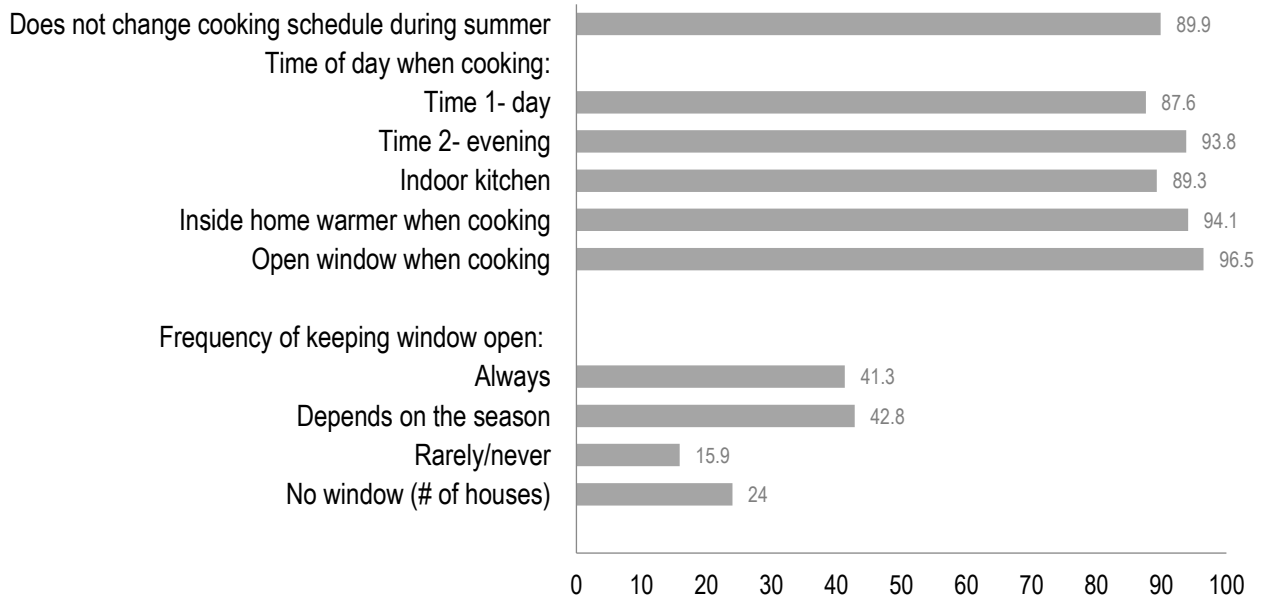


Fig. 12: Degree of exposure to additional heat inside slum dwellings. N=300 households (Tran, 2012). Data collected through the study*, 'Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad'*

5.1.2 Impact of Urban Heat Island Effect on Heat Exposure

An urban heat island (UHI) is an urban area or that is significantly warmer than its surrounding rural areas due to anthropogenic activities. Mortality is more sensitive to heat in urban areas compared with rural and suburban areas as urban heat islands magnify night time temperatures. (Nag & Nag, 2009) In the city of Ahmedabad UHI effect has progressively increased as the built-up areas within AMC limit increased from 171.29 sq. km in January 1999 to 201.94 sq. km in January 2011 (18% increase in 12 years). UHI effect is further increased by the increase in open land as the sandy loamy type of soil in Ahmedabad has a high heat retention capacity. (Bajaj, Inamdar & Vaibhav, 2012). As a result, surrounding land cover influences surface temperature and increases heat retention.

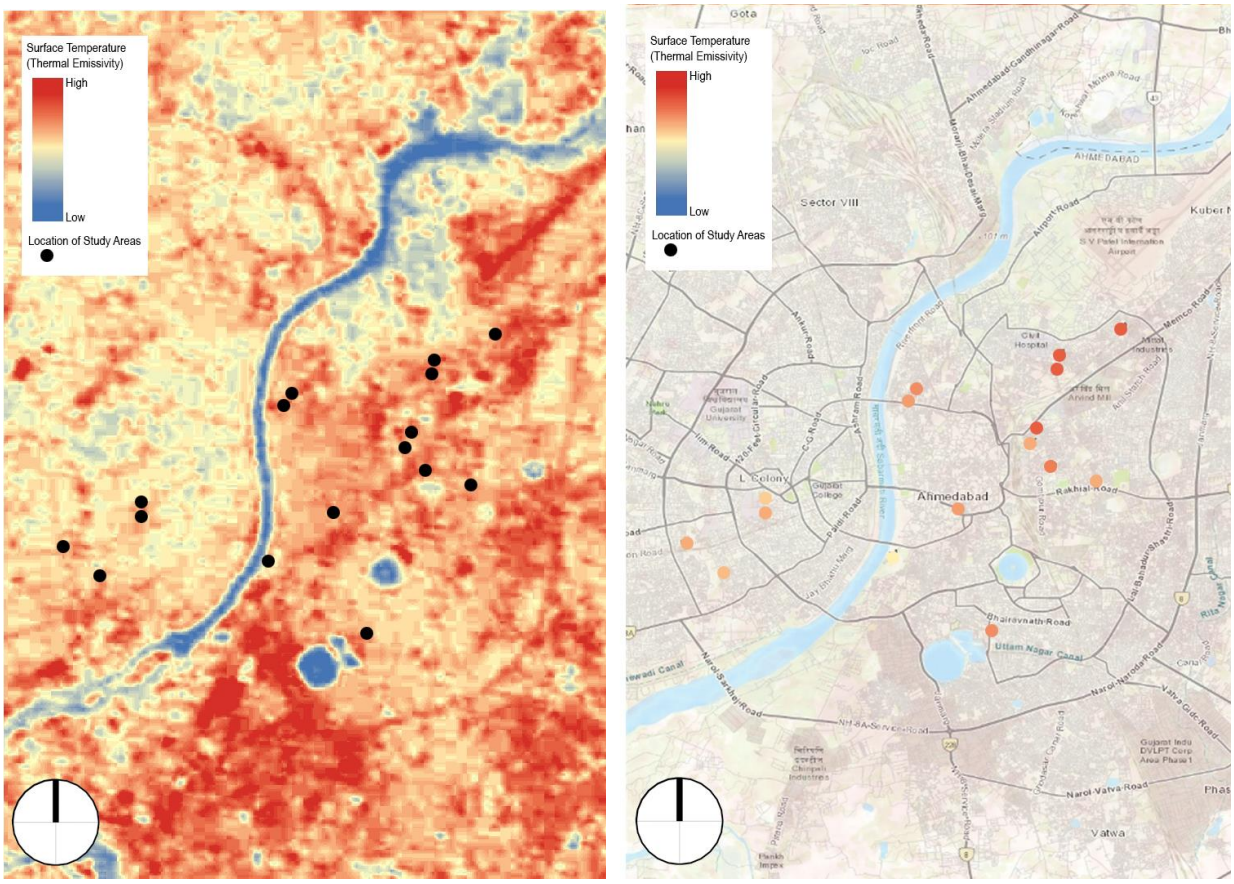


Fig. 13: Surface temperature based on land cover. (Source: Base map-ESRI, Locations- MTH, Surface temperature- Landsat TM 4-5). (Enlarged maps in Appendix 02 and 03)

The map captures the average surface temperature (surface heat emissivity) in different part of the city. The waterbodies have the lowest daytime surface temperature, places with high vegetation and tree cover (such as Ahmedabad cantonment and university area) are relatively cooler and areas with least vegetation and high degree of paved surfaces (airport, highways) have high surface temperatures. Data was acquired from Landsat TM 4-5 satellite. The image was captured on 2011-11- 14 with 30m resolution.

5.1.3 Susceptibility

Young children and the elderly are highly susceptible to heat related illnesses, particularly those with preexisting chronic conditions. Heat related illnesses identified by Ahmedabad Municipal Corporation (AMC) as priority include heat rash (frequently in children), heat cramps, heat exhaustion, heat syncope (typically adults) and heat stroke. (AMC, 2017). Associated with the problems of dehydration, studies show increased occurrence of kidney stones and renal failure for

the elderly, children and also adult workers engaged in physically demanding jobs in hot environments (Nag & Nag, 2009). The survey found 17.8% of the population with pre-existing chronic condition. (Tran, 2012)

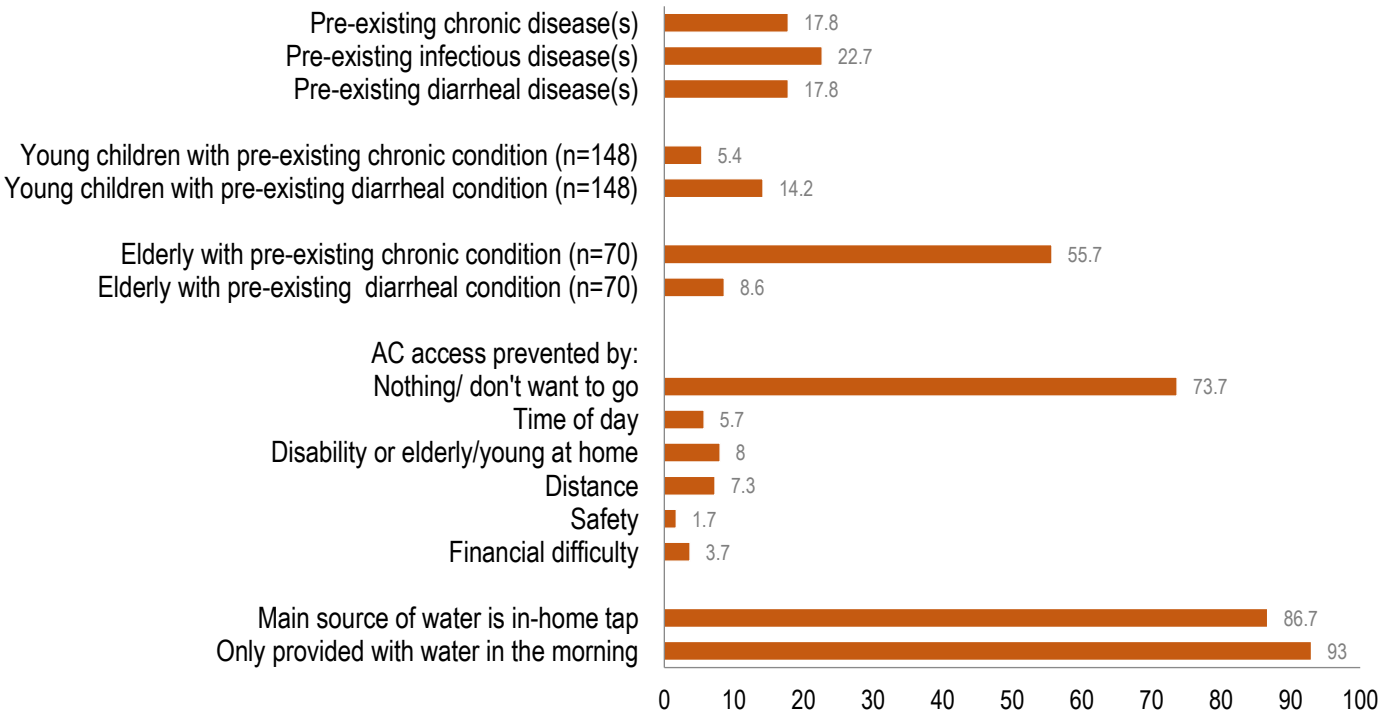


Fig. 14: Degree of susceptibility to heat related illnesses in slums. N=300HH or 1650 people (Tran, 2012).
Data collected through the study, *'Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad'*

5.1.4 Adaptive capacity

When people are exposed to hot environment at a regular basis, the body naturally acclimatized. The physiological acclimatization is primarily an improvement of sweating efficiency the behavioral adaptations to the heat include taking frequent rest breaks in the shade, improving air circulation, reducing physical activity by slowing the pace of work (Nag & Nag, 2009). The survey shows that slum communities have high social cohesion particularly in times of emergency. 98.3 % of the respondents would call upon a neighbor in case of an emergency and 78.7% of the respondents have helped another during an emergency or heat wave. Slum communities have a high degree of awareness related to extreme heat events and heat related illnesses. 90.8% of the respondents reported that they sought information on heat-related illness through media sources. (Tran, 2012)

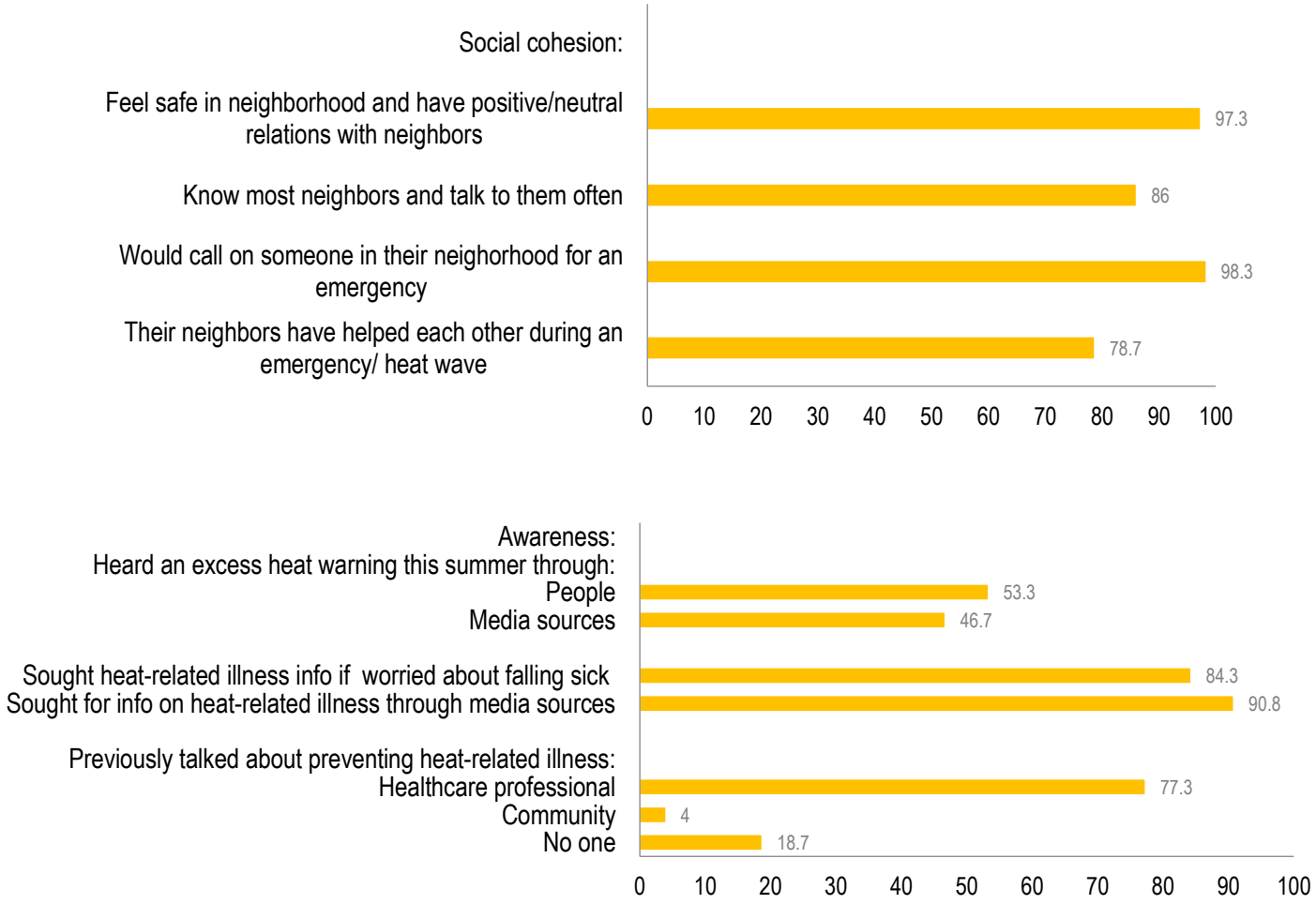


Fig. 15: Adaptive capacity to extreme heat events and heal related illnesses. N=300HH or 1650 people (Tran, 2012) Data collected through the study, 'Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad'

From the survey, it seems apparent that slum dwellers modify their behavior if they have control over it. Large percentage of respondents reported that they stay indoors if they can, drank lots of fluids, took cool showers and protected themselves in transit. However, if no options were available, large percentage of the respondents rarely reduced activity or avoided outdoor activities. (Tran, 2012)

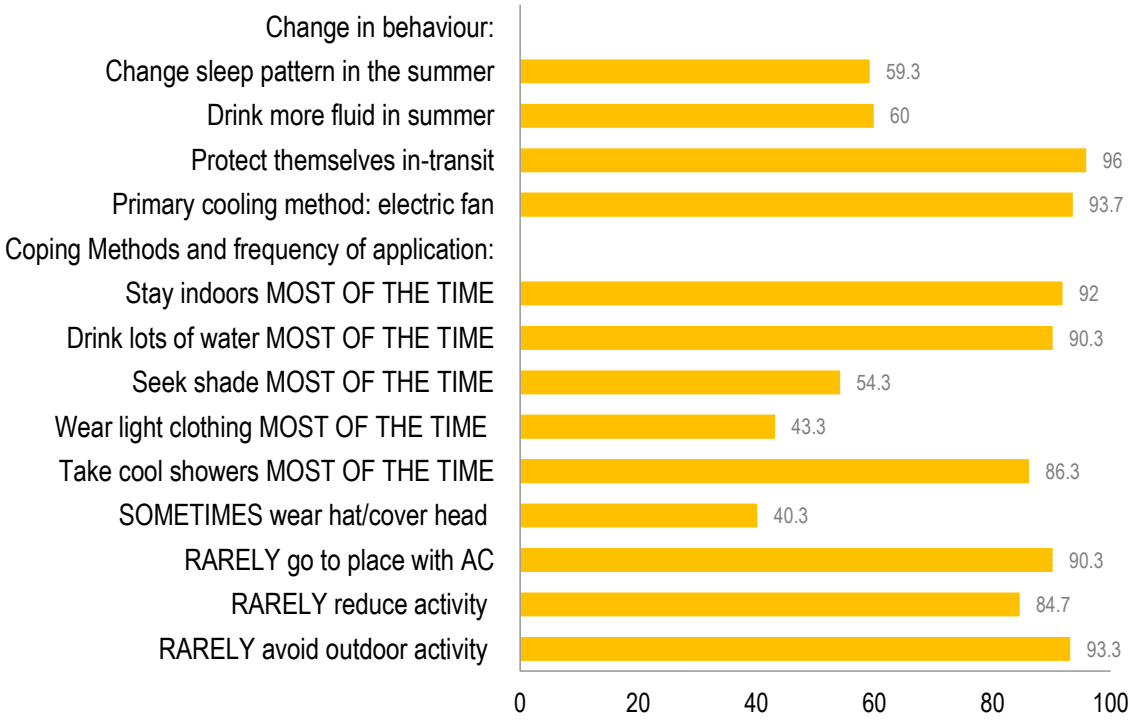


Fig. 16: Adaptive capacity to extreme heat events and heal related illnesses. N=300HH or 1650 people (Tran, 2012) Data collected through the study, 'Assessing Vulnerability to Extreme Heat Among Residents of Urban Slums in Ahmedabad'

5.2 Flooding and Inundation

Between July 1 and 28, Gujarat received 559.4 mm of rainfall and this was 65% above the average rainfall for the same period of time. As of 1 August, 224 people had died due to rain-related causes, 18 of which were in Ahmedabad. (2017 Gujarat flood, 2018) Slum dwellers engaged in occupations such as daily wage labor, construction work, rag picking, etc. loose between 3 to 10 days to 11 days to a month of working days. Recovery in terms of draining of inundated water and house repair ranges between 11 days to a month or more. A considerable number of people change their occupation due to loss of jobs or productive assets (Srivastava & Shaw, 2015). During floods, low income households can lose all their possessions, including their sources of livelihood if the women (or men) work from the house. As very few houses are elevated, flooding into houses is common, even as a result of storm water runoff as opposed to river or stream flooding.

Slums in Ahmedabad are vulnerable to three types of flooding 1) Localized flooding due to inadequate sewer and drainage systems. 2) Overland flooding due to exceedance of sewer capacity and rapid transformation of land use from pervious to impervious surfaces. 3) Fluvial flooding in settlements on the banks of the Sabarmati River or other large water bodies.

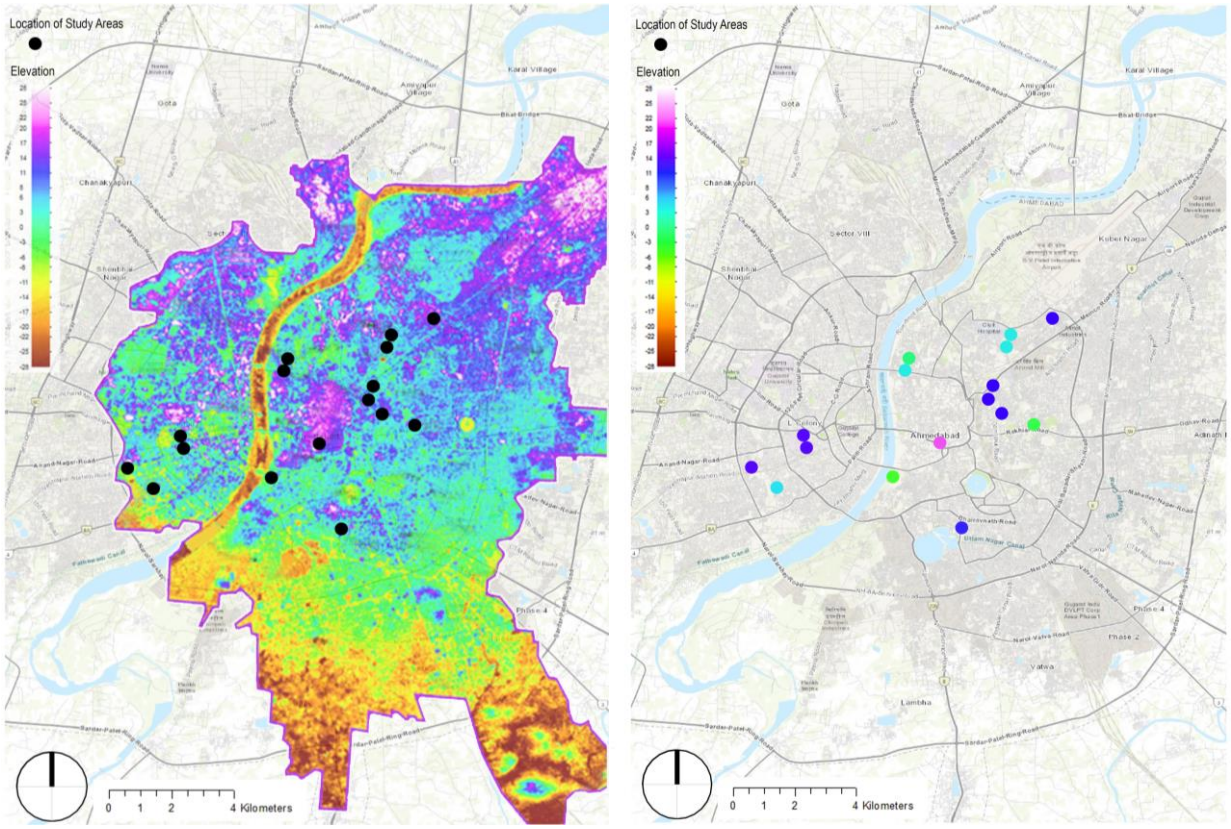


Fig.18: Vulnerability of study areas to overland and localized flooding. (Source: Base map-ESRI, Locations- MTH, Elevation-SRTM). (Enlarged maps in Appendix 04 and 05).

The map assesses vulnerability to localized flooding by identifying relative elevation of the settlements. By definition slums do not have adequate drainage and storm water infrastructure. Hence settlements situated in low lying areas are more likely to be severely impacted by flooding. In the same way, slums situated at lower elevations are bound to become points for overland flood water collection. Overall, the city's topography slopes to the south. Digital Elevation Model (DEM) data was acquired from Shuttle Radar Topography Mission (SRTM) on 11 February 2000. The data resolution is 30m with absolute vertical height accuracy of less than 16m.

5.2.1 Coping Strategies

Slums employ a combination of structural means and complex networks of assistance to recover from floods. The different types of coping strategies used are summarized below.

Structural adjustment such as raising the foundation and filling rooms with soil and other debris is a commonly adopted strategy among slum inhabitants. Slum dwellers, therefore, invest approximately Rs.5000 every 2 or 3 years to raise their rooms and minimize the risk of inundation during monsoon period. As a result, in the same lane of houses a difference in the height of plinths makes some households more vulnerable to excessive inundation in comparison to others.

Another structural adjustment is construction of second floor in wealthier households. Most houses have an elevated platform that serves the purpose of a storage place for all important things in house and to shelter the members of the household in case of flooding. Poor households resort to elevating a board to secure some of the important and expensive items of the household. In some slums, local groups collectively cleaned, widened and covered drains in the settlement before monsoons. However, structural adjustments have limited effect on reducing the risk of floods in slums that are located in places like creek areas, stream channels and other naturally flooding zones. (Chatterjee, 2010)

In the wake of a disaster, another common coping strategy is to temporarily relocate to rural areas. This correlates to assert ownership in villages and family residing in rural areas. (Srivastava & Shaw, 2015)

5.3 Water Scarcity

Gujarat is facing growing problems of water scarcity. The state has limited renewable freshwater and the situation is more precarious when the demands for water from different sectors compete with one another for the limited supplies. When priorities clash, widespread conflict emerges for allocation towards farming of water-intensive cash crops, industry and urban, and rural use. (Kumar & Singh, 2001).

On February 1st 2018, with severe water crisis looming large over Gujarat, the state government, decided to rationalize drinking water supply to the cities. This is in addition to limiting water for irrigation and industries from March 15th. Water

supply to Ahmedabad, which receives 1840 million liters per day (MLD), was reduced by 200 MLD. Currently, Gujarat has only 49.8% water of its total storage capacity. This is 13% less as compared to last year. One of the major triggers of water crisis is the lowest rain water inflow in 15 years in Narmada catchment areas. (Kapil, 2018)

These restrictions are put in place to ensure adequate water supply until the onset of monsoon in June. Two issues loom at large

1) How will the municipality ration water supplies? How will the vulnerable population compensate this loss?

2) the most severe period of drought coincides with peak summer. In the month of May, how will the vulnerable population cope with two prolonged climate stressors?

5.3.1 Sources of Water Supply

The city demands 1840 million liters per day (MLD) of treated water. The different sources are listed in the table below. Since 2000, the Narmada canal of the Sardar Sarovar project has become a significant source of water. This development has slowed groundwater depletion to a certain extent, but groundwater extraction is still widespread, especially in areas not provided by municipal water supply. (Iyer et al., 2014).

Source	Volume (MLD)	Type of water source
Narmada main canal	330	Surface
In take well I at Kotarpur	165	Ground
In take well II at Kotarpur	330	Ground
Dholka branch canal	275	Surface
Sabarmati river	70	Surface
Shedhi branch canal	200	Surface
French wells - 7Nos	170	Ground
Bore-wells	300	Ground

Table 10: Sources of water for the city. (AMC, 2018)

5.3.2 Water Supply and Slum Communities

In 2011, a statewide Performance Analysis System (PAS) was employed to understand water supply with in slums. 15,000 slum households were surveyed across the state. It is apparent from the survey that 5% of the residents have no access to municipal water supply, 67% of the households have a tap inside the premises and only 72.9% of the households receive water supply every day. (CEPT, 2011)

Slums	Status
% of households with access to municipal water supply	94.7
% of households dependent on shared municipal water connections	12.6
% of households dependent on community stand post	18.7
% households with access to a tap on premise using municipal water supply	66.6
% of households with daily water supply	72.9

Table 11: Water supply and slums across the state (CEPT, 2011)

In the state, water tax is embedded into property tax. As slum dwellers, usually do not have title to the land they occupy, they have no claim in making demands for increase in water quantity or better quality. Water services that are provided within these communities are done so free of charge. This system disenfranchise communities from making rightful claim to clean and sufficient water resources.

The per capita availability of water supply is quite low for people living in slums. Hirway in her study found that some slums in the city of Ahmedabad have access to as low as 5 liters per day for each member. This is well beneath the city level mean consumption of 410.9 liters. In contrast, wealthy neighborhoods enjoy 500 liters per person. 100 times more than a slum dweller! (Hirway, 2005). In times of scarcity, this water resources become even scarcer.

Household type	Volume (liters per capita per day)	Source
Slum house hold	7-8	(Hirway,2005)
High income house hold (e.g. Sahibag neighborhood)	500	(Hirway,2005)
Average domestic consumption across the city	410.9	(Shaban, & Sharma, 2007).

Table 12: Volume of water consumed based on type of household.

When water is scares, wealthier sections of society can afford to purchase portable water. The table below presents the amount of money spent on portable water in the year 1999-2000 in the city.

Type	Amount of Rs. in crores
Private Tankers	30.2
One liter bottled water	64.5
Water pouches	24

Equipment for purifying water (e.g. charcoal filter)	214

Table 13: Money spent on portable water in 1999-2000. (Hirway, 2005)

Wealthy households can compensate for the loss of usual quantity of water during the rationing season by purchasing water at a higher price. Water is purchased from private vendors or from the municipality itself. It is delivered through tankers. Slum dwellers lack the affordability and, in most cases, even the storage space necessary to purchase water.

5.3.3 Impact of Scarcity on the Community

Procuring water is especially challenging in slums that are not covered by the public network, and women bear the burden of procuring water for the household. (Baruah, 2007). Community members rarely know when or where a tanker will appear. They know only that they must be prepared if and when it does, and that they need sufficient space in their homes to store large capacities of water—in case the tanker doesn't return for several more days. No one is accountable for the route, delivery schedule or frequency of delivery. Women in particular are affected by this uncertainty. (IMTFI, 2002)

A kind of order does exist amidst the chaos that erupts when a tanker makes a delivery. There's something of a hierarchy around who gets to fill their containers first, and all the shouting is a way of enforcing that order, so no one steps out of line. And yet, no matter what the residents have done over the years, the fact remains that water is delivered largely at the discretion of the suppliers, and more specifically the drivers, who themselves must react to traffic patterns, road problems and other unforeseen obstacles. (IMTFI, 2002)

5.4 Vector Borne Deceases

Vector borne diseases such as Malaria, Dengue and Chikungunya are endemic and major public health concerns in Ahmedabad. (Urban Management Centre (UMC), 2013). These are illnesses that are transmitted by vectors, which include mosquitoes, ticks, and fleas. These vectors can carry infective pathogens such as viruses, bacteria, and protozoa, which can be transferred from one host (carrier) to another. The seasonality, distribution, and prevalence of vector-borne diseases are influenced significantly by climate factors, primarily high and low temperature extremes and precipitation patterns. (Beard et al., 2018). In the case of Ahmedabad, cases of malaria are higher during monsoon season (July to September), whereas Dengue though is reported throughout the year, is more rampant after the

monsoon (September to November). (Urban Management Centre (UMC), 2013). This trend can be observed in the graphs below:

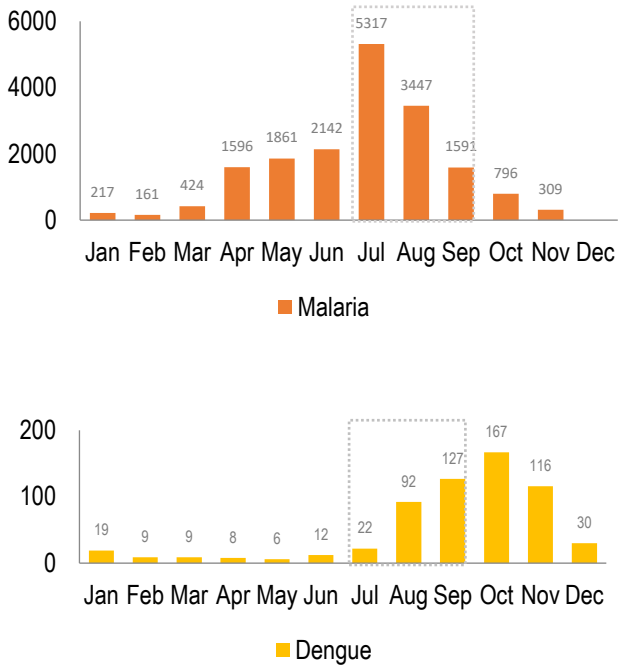


Fig.15: Number of cases reported in the year 2012. (Urban Management Centre (UMC), 2013).

5.4.1 Impact on Slum Communities

The spatial distribution of diseases in the city reveals a concentration of both water and vector-borne diseases in the oldest part of the city, which has a higher concentration of both small-scale industries and lower-class informal settlements. While the oldest part of the city remains an incubator for various diseases, the middle- and upper-class residents living in the western part of the city are equally impacted by vector borne deceases. Although, middle- and upper-class residents may receive better water supply and have adequate sanitation, their built environment is not sanitary enough (due to the lack of civic amenities, waterlogging and inadequate disposal of solid waste) to prevent breeding of vectors (Saravanan, 2013).

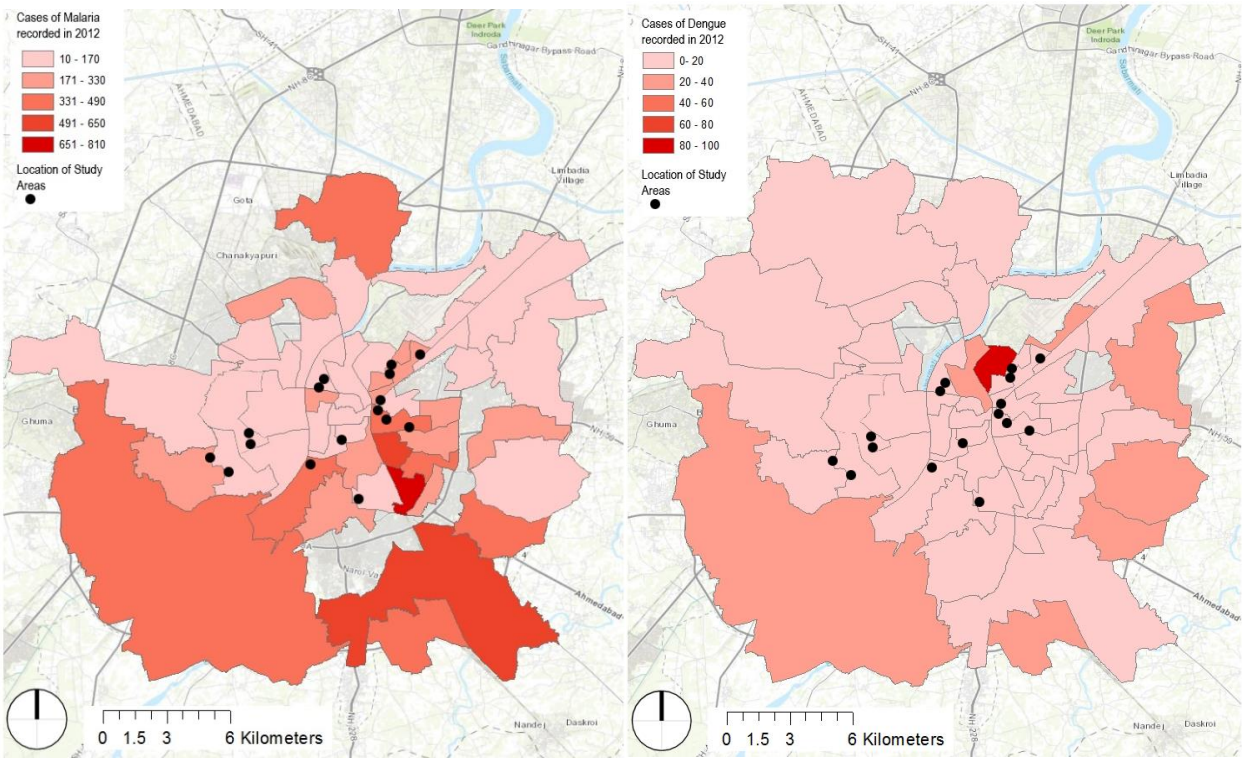


Fig.16: Cases of malaria and dengue recorded in 2012. (Source: Base map-ESRI, Locations- MTH, Ward boundaries- ArcGIS online, Number of cases- UMC) (Enlarged maps in Appendix 07 and 08).

As part of the 'Malaria Free 2022' state wide campaign, AMC conducted a 16 day inspection of breeding sites through this, 29,402 mosquito-breeding sites were identified across the city. Notices for presence of mosquito breeding sites were issued to 17 commercial establishments and construction sites and an additional administrative charge was levied for noncompliance. The establishments ranged from schools, shopping malls to households. (TNN, 2017) & (The Indian Express, 2017). Cases are prevalent across all sections of society.

Despite the prevalence of the deceases, its burden is not equally distributed across society. Slum households disproportionately bare both the economic burden and impact on health.

Economic burden: Average monthly household income for a slum dweller in 2004, was Rs.3105.20. If a person was infected by malaria, the treatment cost would amount to Rs.241 and wages lost would be Rs.1001. In total, the person would lose Rs.1242 which is 40% of their monthly income! On the other hand a wealthy person would lose less than 5% of their monthly income. (Gupta & Chowdhury, 2014)

	Treatment cost (average per capita per month), rupees					
Categories	Outpatient care	Hospitalization	Others (Transport, Lodging etc.)	Total	Work days lost	Loss of earnings (average per capita per day), rupees
Poorest	167	46	28	241	11	91
Richest	210	135	26	370	8	158

Table.15: Direct and indirect cost of illness from malaria, 2004. (Gupta & Chowdhury, 2014)

In addition to this, wealthy households have better access to quality health care providers and other financial options (i.e. savings) to depend upon. Thus, even with subsidized treatment options, slum households are likely to be disproportionately burdened by expenses.

Health burden: Slum dwellers are likely to experience more adverse impact on their health than other households. This is due to two reasons 1) their health condition is already compromised by other acute health conditions 2) they are likely to be suffering from malnutrition and other vitamin deficiencies. Although no studies investigate the slum population health compared to wealthier sections of the city, more specific studies reveal an underlying compromise in basic health condition.

Condition	**Percentage affected**	**Sample size**	**Population Characteristics**	**Source**
Morbidity				
Acute diarrhea	3.7	1389	254 households	(Mihir & Geeta, 2010)
Acute respiratory infections	7.4	1389		
Fever	5	1389		
Anemia (Women)	5	690		
Anemia (Men)	13	699		
Worm infestation	3	1389		
Tuberculosis	30.4	210	Children below the age of 15	(Bhagyalaxmi et al., 2003)
Malnutrition and deficiency				

Vitamin A deficiency	2.9	1000	Between the age of 5-15 years	(Chauhan et al., 2011)
Undernutrition	60.5	744	372 child-mother pairs	(Solanki et al., 2014)
Underweight children	42.7	372		
Children showing signs of stunting	50	372		

Table.16: Overview of studies on morbidity, malnutrition and nutrient deficiency in slums.

Thus, slum dwellers are likely to take longer to recover from vector borne illnesses.

6. Assessment of Baseline Condition- At the Slum Level

6.1 Slum Typologies

Studies of informal settlements use different criteria to classify informal settlements within Ahmedabad. Mahadevia et. al distinguish informal housing into two typologies- squatter settlements and *chawls*. The census of India, classifies informal housing based on its status of recognition as 'notified' or 'non-notified'. Based on its urban morphology, Ballaney classifies informal housing into 1) organic low dense, 2) relocated slums, 3) organized row house, 4) organized cluster, 5) organized dense slum and 6) formal low cost housing. (Ballaney, 2014).

For the purpose of this study slums are classified based on two key criteria that directly impacts susceptibility. These are relative location of the settlement and the quality of built environment. Settlements located on vulnerable sites (such as river fronts) are more likely to be impacted by climate change. On the other hand, quality of built environment in terms of spatial organization and construction material directly impacts coping capacity of communities and reduces susceptibility. In this study, slums are classified into 5 typologies 1) squatter settlements 2) relocated slums 3) *chawl* 4) *pol* and 5) slums located on the river front. In the following sections an example from each topology will be assessed on its vulnerability to the 4 key climate stressors.

Fig.18: View of the 16 study sites

6.2 Criteria and Weightage for Assessment

The criteria and weightage for assessing susceptibility to the key climate stressors are listed in the table below. Criterions are divided into those that aggravate exposure and coping mechanisms. A combination of existing demographic data and remote sensing exercises were used to deduce these.

Susceptibility to heat wave is measured through extent of exposure and coping strategies. Level of exposure is gauged by relative surface temperature, North-South orientation of settlements, and percentage of houses with tin roof. Relative surface temperature is gauged through Landsat TM data. The orientation of the settlement is assessed through aerial imagery. There is higher heat gain if the major axis is along east-west orientation and this increases exposure. The fraction of houses with tin roofs is assessed either through its spectral signature on aerial imagery or existing data on the settlement. Tin roofs trap more heat compared to concrete or thatch roof and this increases exposure.

Coping strategies to heat waves include access to shaded and open spaces, access to electricity and percentage of green spaces within the community. Access to shaded and open spaces is gauged through a landuse classification of the aerial imagery. Although access does not guarantee entrance, proximity to open and shaded spaces (within 700m-walkable distance) provides an opportunity to cope with the heat. Access to electricity is deduced through existing data on the settlement. Although access does not guarantee continuous supply or affordability, mechanical ventilation increases coping capacity. Percentage of green spaces within the community is measured through Normalized difference vegetation index (NDVI) analysis of aerial imagery. Any vegetation within the community appears is revealed and the redness of the vegetation signals its health. Green spaces within communities provides shade, improves ventilation and increases coping capacity.

Susceptibility to heat wave:

Criteria	Weightage (Value)	Note
Exposure:		
Relative surface temperature	High (3) Medium (2) Low (1)	
North -South orientation of settlement	No (1) Yes (0)	More heat gain if major axis is along East- West orientation.
Percentage of houses with tin roof	High (3) Medium (2) Low (1)	Tin roof traps more heat compared to RCC and thatch.
Coping strategies:		
Access to shaded and open spaces	No (1) Yes (0)	Proximity does not guarantee access. (could be a private property)
Access to electricity	No (1) Yes (0)	Does not guarantee continuous supply or affordability.

Percentage of green spaces within community	High (3) Medium (2) Low (1)	

Susceptibility to flooding and inundation is measured through extent of exposure and coping strategies. Exposure is deduced by assessing if the settlement is located in low lying areas or if its located in close proximity to large water bodies. Relative elevation of the community is measured through digital elevation model (DEM) data and proximity to water bodies is gauged through land use classification of aerial imagery.

Coping strategies to flooding and inundation includes presence of underground drainage system, presence of multi-story buildings within the community, proximity to pervious surfaces for infiltration, and percentage of green spaces within the community. Information on the presence of underground sewer system was referenced through existing data on the settlement. The presence of multiple story building was gauged by shadow analysis of aerial imagery. Overlapping shadows, particularly on rooftops of lower buildings, signals presence of multiple floors. Residents on lower floors can take refuge in the upper floors until water levels subside. Although, it does not account for soil type or topography, percentage of open spaces or green spaces with in the community indicates potential space for water infiltration. This is gauged through an NDVI analysis of aerial imagery.

Flooding and inundation:

Exposure:		
Situated in low lying areas	Yes (1) No (0)	
Situated near waterbodies	Yes (1) No (0)	
Coping strategies:		
Presence of underground drainage system	No (1) Yes (0)	
Presence of multiple story	No (1) Yes (0)	Residents on lower floors can take refuge in the upper floor till water levels subside.
Proximity to pervious surfaces (infiltration)	No (1) Yes (0)	Does not account for soil type and topography suitable for infiltration
Percentage of green spaces within community	High (3) Medium (2) Low (1)	Does not account for soil type and topography suitable for infiltration

The susceptibility to vector borne deceases is measured through extent of exposure. Exposure is measured through prevalence of malaria and dengue cases in the ward area in prior years, proximity to open water bodies and presence of dense vegetation around the community. The number of dengue and malaria cases in the year 2012 was registered with Ahmedabad Municipal Corporation (AMC). This data was spatially correlated with GIS and prevalence at the ward level was mapped and exposure was measured through this. Both proximity to open waters and presence of dense vegetation was deduced through land use classification of aerial imagery. Both these factors are correlated to the presence of vector habitats.

Vector borne decease:

Exposure		
Cases of Malaria recorded in the ward in 2012	High (3) Medium (2) Low (1)	
Cases of Dengue recorded in the ward in 2012	High (3) Medium (2) Low (1)	
Proximity to open water	Yes (1) No (0)	
Presence of dense vegetation around the community	Yes (1) No (0)	

Susceptibility to water scarcity can only be measured by one coping strategy. Although this does not guarantee continuous water supply, particularly in the summers, access to municipal water supply either through direct supply to houses or community water taps indicates resilience to scarcity. This data was referenced from existing studies on the settlements.

Water Scarcity:

Coping strategies		
Access to municipal water supply	No (1) Yes (0)	Does not guarantee continuous supply

Table.16: criteria and weightage for assessing susceptibility.

Sources of information referenced is included in appendix 10.

6.3 Slum Typology -1 Squatter Settlements

Squatter settlements are those developed on illegally appropriated lands, often public lands, low-lying lands, river-beds or lands acquired for public purpose. Settlements are also developed on private lands without required planning and building permits. (Mahadevia, Desai & Vyas, 2014). The typology is characterized by random clustering of households and high density

Fig.19: Study sites identified as typology 1 and their location

An example of this typology is *Rajiv Nagar*. Located in the west side of the city, the slum houses 14081 households. Most households have access to toilets and 70% have access to tap water inside their household. 50% of the houses are *pakka* construction (brick and concrete houses) but 92% of all houses have concrete roofs.

Relative to other typologies, squatter settlements are likely to face localized flooding. Theoretically, all houses have access to municipal water (either through individual taps or common water facilities) but it's unsure if they receive continuous water supply. The green and open areas that surround the community increases the chances of vector borne decease cases.

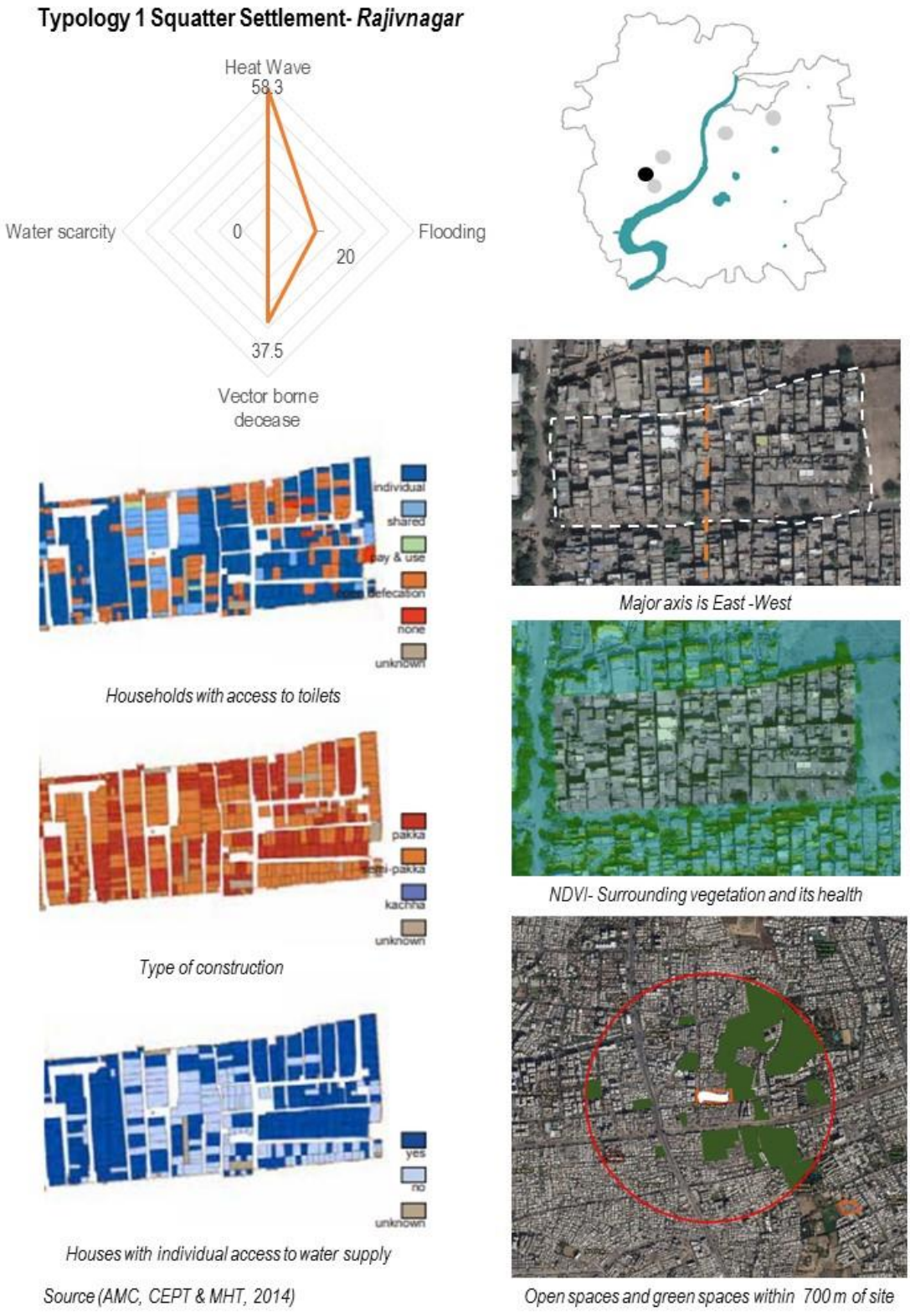


Fig.20: Analysis of Rajiv Nagar.

6.4 Slum Typology - 2 Relocated Slums

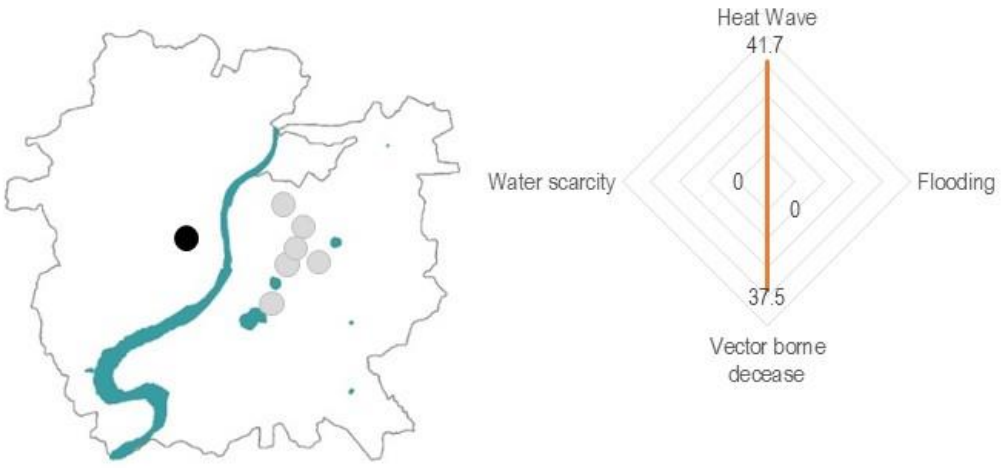
Across several city and state wide rehabilitation schemes, slum communities were relocated to permanent housing. Although these communities continue to live within the same socio economic standards as they previously did, the quality of their built environment increased exponentially. These apartments are usually 4 story high, with indoor toilets, municipal water and drainage connection. The distinct and repetitive geometry of building footprint and organization on site facilitates easy identification through remote sensing data.

Fig.21: Study sites identified as typology 2 and their location.

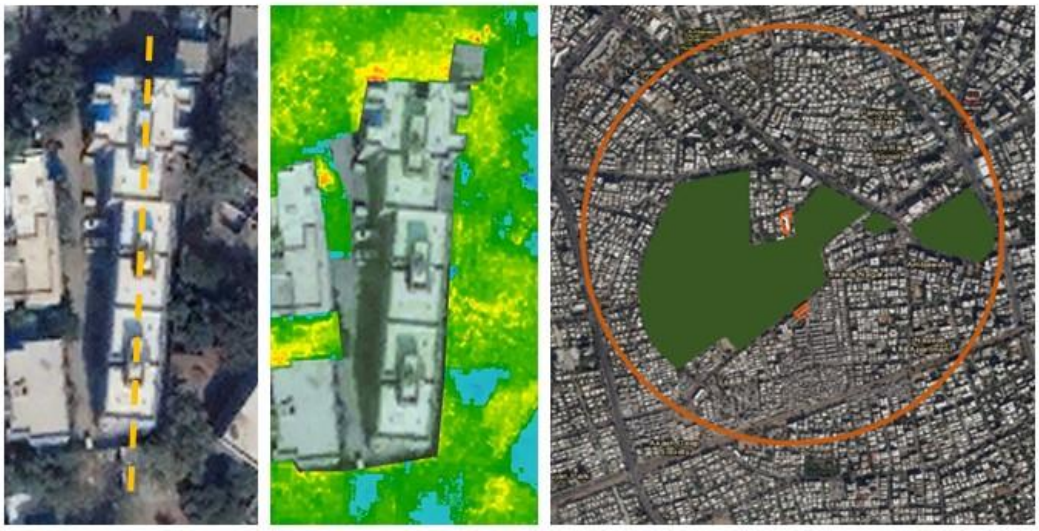
An example of this is *Abhuji na Chappra*. Under the Slum Rehabilitation Scheme, Abhuji na chapra was upgraded into 3 four story apartments with 56 units in October 2014. The developer was given additional Floor Space Index (FSI) on another project. (Mahadevia, Bhatia & Bhonsale, 2014). (For further analysis, see Fig. 20)

Rehabilitated slums rank low in susceptibility to water scarcity. This is because each house is provided with provisions for municipal water supply. However this does not guarantee continuous supply particularly in summer. This typology also ranks low in susceptibility to flooding. This is because proper storm water drainage is planned at the site scale. Moreover, since these apartments are multi-story, residents in the lower floor can cope by taking refuge in the upper floors. These communities reside in significantly better living conditions and built environment.

Typology 2 Relocated Slums- *Abhuji na Chhapra*



Before construction in 2013 *Site after construction in 2017* *Typical floor plan*



Major axis is East -West *NDVI- Surrounding vegetation and its health* *Open spaces and green spaces within 700 m of site*

Fig.22: Analysis of Abhuji na Chhapra.

6.5 Slum Typology - 3 *Chawls* or *Chali*

The term '*chawl*' refers to tenement-style 4-5 story buildings, with shared latrines, originally constructed to meet the housing demands of the migrant textile workforce. Due to the Rent Control Act in 1947, the rents levied on these units were frozen. As a result, the owners were either not interested in collecting the nominal rents or sold the units. With such low rents the units were not properly maintained, leading to their deterioration and dilapidation. Most *chawls* are concentrated in the North and East zones in close proximity to the former mills. (Mahadevia, Desai & Vyas, 2014).

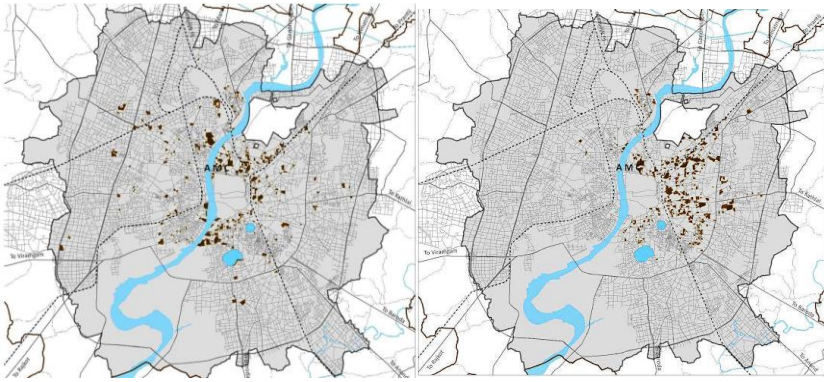


Fig.23: Location of Slums (right) and location of Chawls (left) as documented by AUDA in 2013 (Mahadevia, Desai & Vyas, 2014).

Fig. 24: Study sites identified as typology 3 and their location

Chawls rank high in susceptibility to heat waves. This is because of their close proximity to large areas of impervious surfaces such as the airport. They rank lower in susceptibility to flooding, this is because the terrain gradually slopes towards the south. However, there is significantly less pervious surfaces for infiltration.

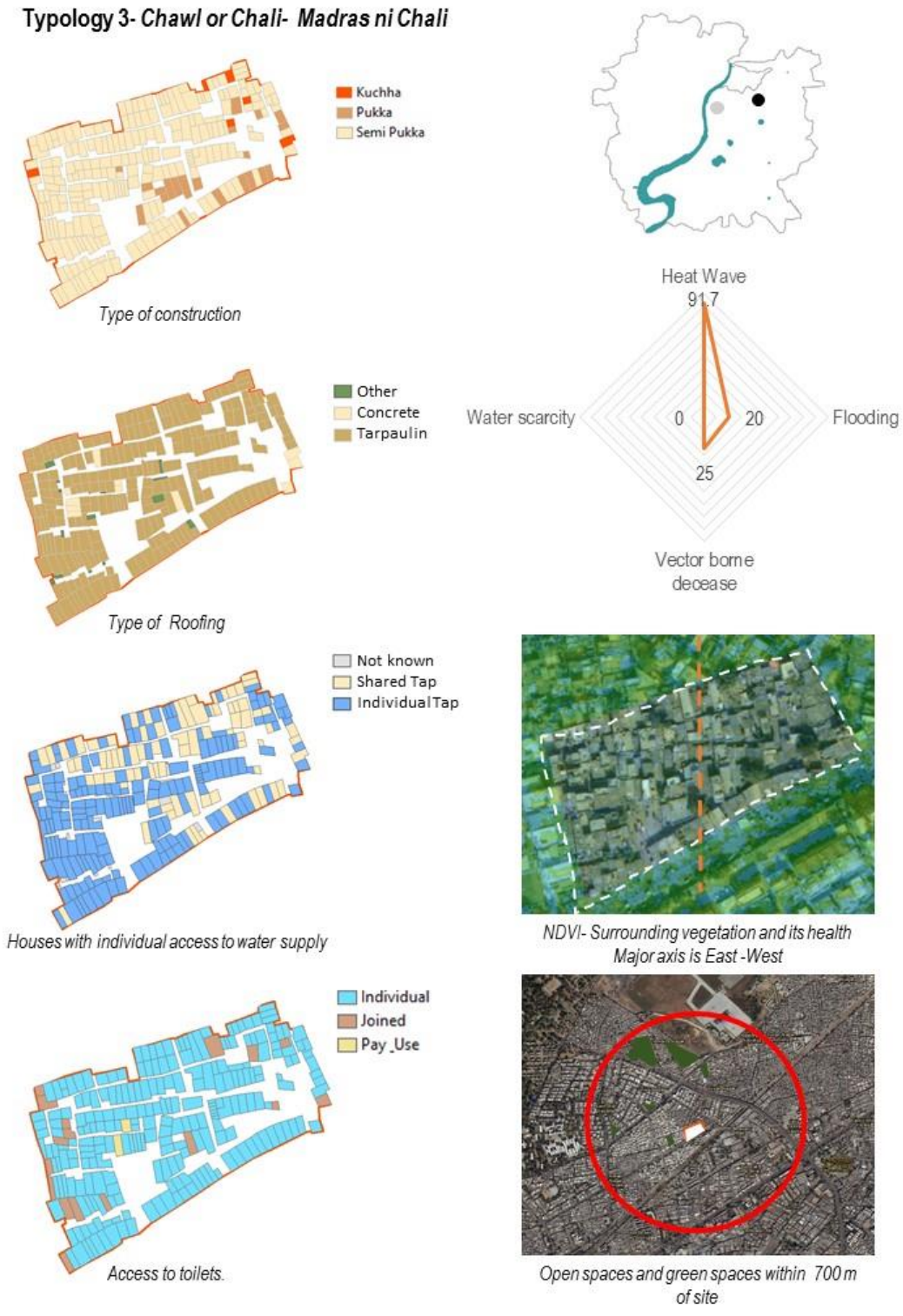


Fig.25: Analysis of Madras ni Chali.

6.6 Slum Typology - 4 -*Pol*

The historic city of Ahmadabad is characterized by an urban pattern, consist of three scales of community based settlement: the neighborhood 'Pur', the sub neighborhood 'Pol' and a house. Pol houses is considered as a primary housing typology built for more than 300 years in the city of Ahmadabad. The pol settlement pattern has a rural origin prevalent in the villages of North Gujarat. (AID - Pol houses, 2018)

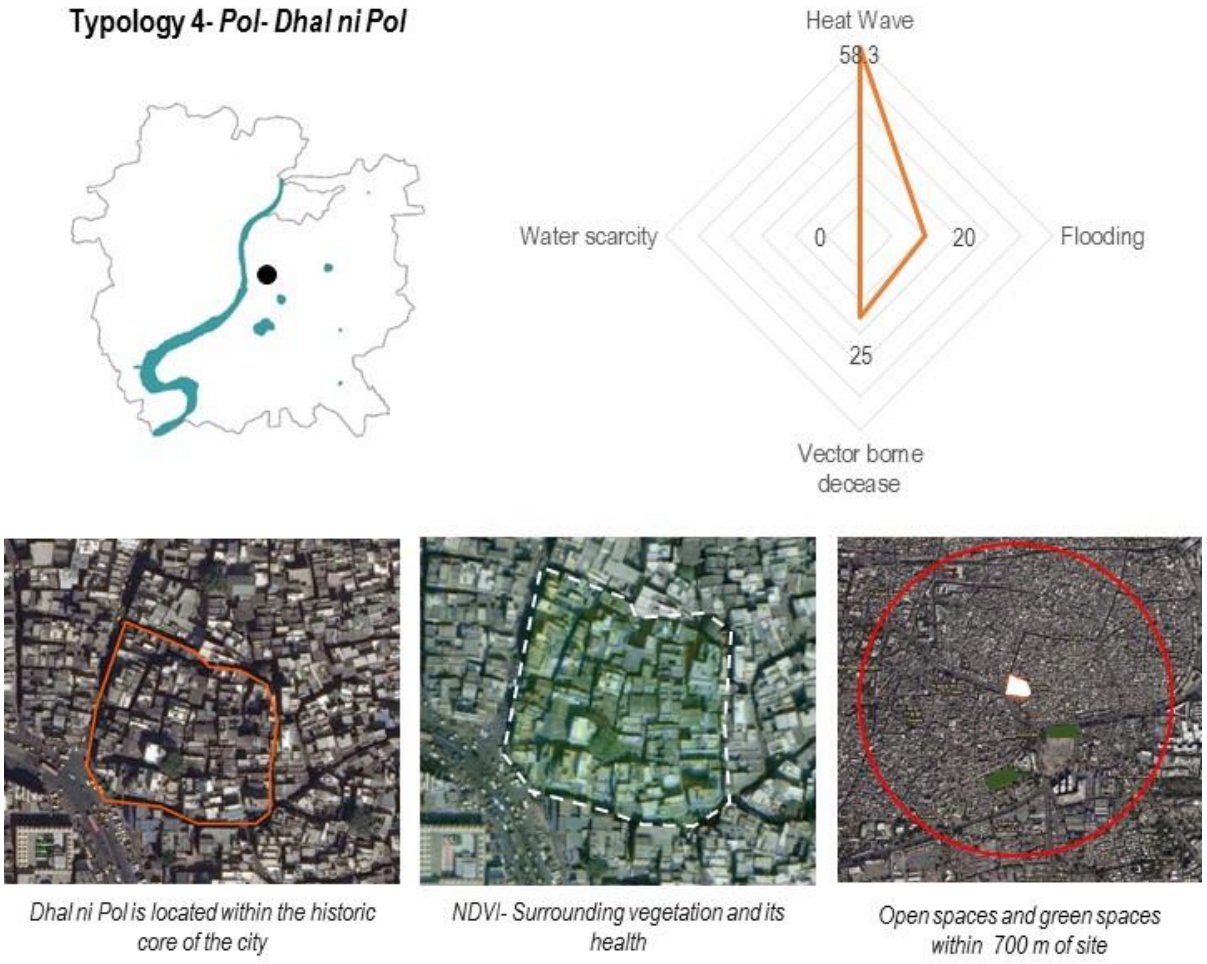


Fig. 26: Study sites identified as typology 4 and its location and analysis

As the city expanded rapidly around the Pols, they are particularly vulnerable to overland flooding. Lack of greenspaces in and around the historic core makes coping to heat waves difficult. In general the historic houses are difficult to maintain and expensive to conserve/ restore. Slums located in pols are additionally challenged by this.

6.7 Slum Typology - 5 Hazard Prone Areas (River Front)

Slums located on the banks of the river and more susceptible to flooding and vector borne deceases due to its location. On the other hand, they are least susceptible to heat waves due to their close proximity to open spaces and water bodies

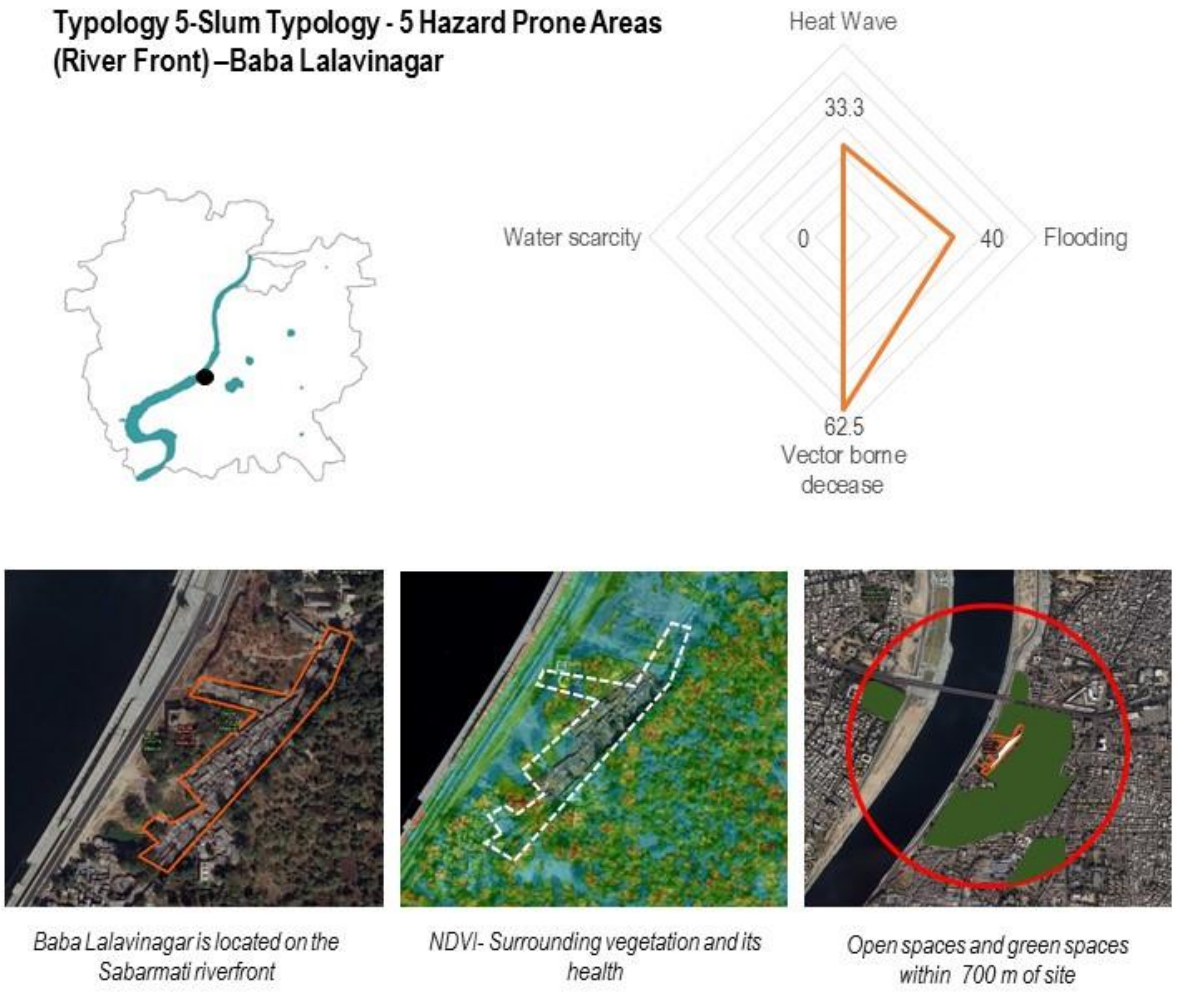


Fig. 27: Study sites identified as typology 5 and its location and analysis

7. Existing Policy Measures and Future Recommendations

This section discusses existing policies and programs that focuses on specific vulnerabilities as a way of assessing gaps in existing programs. Based on these recommendations have been framed.

7.1 Policies Addressing Slum Redevelopment

Relevant policies at the national, state and municipal level have been summarized in the table below-

At the National Level	
National Urban Housing and Habitat Policy (NUHHP) 2007	• The national plan focuses incorporating private sector in slum rehabilitation. • Recommends policies to incentivize the industrial sector for labor housing and the services/Institutional sector for employee housing.
Basic Services for Urban Poor (BSUP)	• AMC and AUDA constructed 32,842 dwelling units under BSUP across more than 25 sites. • The dwelling units are of 28 sq.m. Built-up area and have been built as G+3 / G+4 buildings. Each dwelling unit is provided with water supply, sewerage and electricity connection. • Financial mechanism- 50:20:30 (Central government : AMC: Beneficiary) • This was primarily used to resettle families displaced in other urban projects such as the Sabarmati River Front Development.
At the State Level	
GTPUD Act, 1976	• AMC is required to reserve land for low income housing in the TPS
The Regulation for the Rehabilitation and Redevelopment of the Slums 2010	• In-situ redevelopment of slums (irrespective of their landownership) through the participation of the private-sector. • A dwelling with all basic facilities will be provided to all dwellers in multi storey apartments. • The remaining undeveloped land will be acquired by the developer at market rate and developed for profit. • Developers are also eligible for TDR (transfer of Development Rights) in commercial areas if they construct apartments for slum dwellers in-situ. • By October 2013, around 12 slum rehabilitation projects were under various stages of implementation across the city of Ahmedabad.
At the City Level	

Slum Networking Programme (SNP)	• During 1996-2009, the AMC implemented a pro-poor housing programme called SNP • It organized in-situ upgradation of slums through provision of basic services such as water connections, individual toilets and drainage lines, street lights and paving of internal roads. • Around 60 slums were upgraded, covering 13,000 households.
Slum Sanitation Schemes	• In 1980s AMC launched the 80:20 individual toilet scheme. • AMC contributed 80% of the construction cost and the beneficiary contributed the remaining 20%. • Aproximately 3000 households were covered • In 1990s the AMC launched a 90:10 individual toilet scheme. AMC's contribution increased to 90% • Approximately 14000 households were covered under this.

Table. 17: Policies adopted to develop slums. (Mahadevia, Desai & Vyas, 2014).

It is imperative to note that none of these programs evaluate the potential impact of climate change. Even if implemented these are likely to run into unforeseen complications in the near future. It is recommended that each of these plans include a component of climate change analysis and incorporate guidelines to best address this.

7.2 Policies to Address Heat Waves

Ahmedabad launched the first 'Heat Action Plan' in 2013 and a 5th plan in 2017. The plan outlines strategies to reduce exposure, susceptibility and improve adaptive capacity.

Exposure: The plan outlines a comprehensive early warning system used during heat waves, a robust public education campaign about how to avoid harm from excessive heat and inter-agency coordination to alert residents of predicted high temperatures. Public warning messages about extreme heat days will be displayed on electronic display boards in the city used for public notices. (AMC, 2017)

Yellow Alert	41.1- 43°C
Orange Alert	43.1-44.9°C
Red Alert	>45°C

Fig.28: The messages will be transmitted via orange and red alert warnings on public LED boards (AMC, 2017)

Susceptibility: It proposes to decrease susceptibility by providing water tankers to slum dwellers and limit non-essential water use during extreme heat events. Inter-agency coordination will also ensure that summer vacations are extended (if needed) to protect school going children. (AMC, 2017)

Adaptive capacity: The government will issue advisory to

- Businesses/ construction sites: Provide adequate water and shade to workers and shift work hours to cooler hours.
- Utility companies: Maintain power to critical facilities and vulnerable groups.
- Transport officer: Provide bus stops as sites of shade and water distribution
- Parks: Extend open hours of parks and gardens so they can serve as cooling centers
- Libraries/Religious centers: Keep these centers open as cooling centers
- Mobile service providers: Send SMS notifications. (AMC, 2017)

The plan initiated a "cool roofs" campaign through which roofs of slum dwellings are painted white. Simple steps such as painting roofs with lime-based white wash, adding tarp-like coverings or white ceramic tiles—low cost, high-impact measures—can help bring roof surface temperatures down by as much as 3°C and reduce indoor temperatures by 3 to 7 °C. (Kaur, 2017)

In addition to the existing policies, incases of extreme heat, communities should identify closest 'cool spots' to take refuge in, particularly at night. Some communities may have public amenities such as gardens or parks in close proximity. Others should negotiate access into community centers such as public schools or religious spaces.

7.3 Policies to Address Flooding

Three major strategies have been adopted to address the issue at different scales. These are a state level action plan, relocation of slums from flood prone areas and in-situ improvement of drainage and storm water management.

Gujarat State Hazard Specific Action Plan: The plan outlines protocols concerning declaration of disaster, forecasting and early warning, trigger mechanism for plan activation, response mechanism and relief measures. Specifically for slum communities, the plan mandated a community based flood forecasting and warning system to be developed so that everyone receives information (particularly in relation to evacuation) as soon as possible. Methods for decimation of information may include church bells and temple audio speakers along with conventional media sources. The plan also mandates training individuals within the community to understand extent of previous floods, cause of local flood, time it takes to inundate and time it the inundated water takes to drain. The involvement of community members also helps to prevent vandalism and damage to installations going unreported. (GSDMA, 2015)

Relocation from flood prone areas: The largest relocation and resettlement project was undertaken during the construction Sabarmati river front project. The project aimed to resettle over 10,000 slum households along the banks of the river. The relocated households were given a permanent, titled housing in one of the many relocation sites interspersed within the city's boundaries. (Rehabilitation & Resettlement I SABARMATI, 2018)

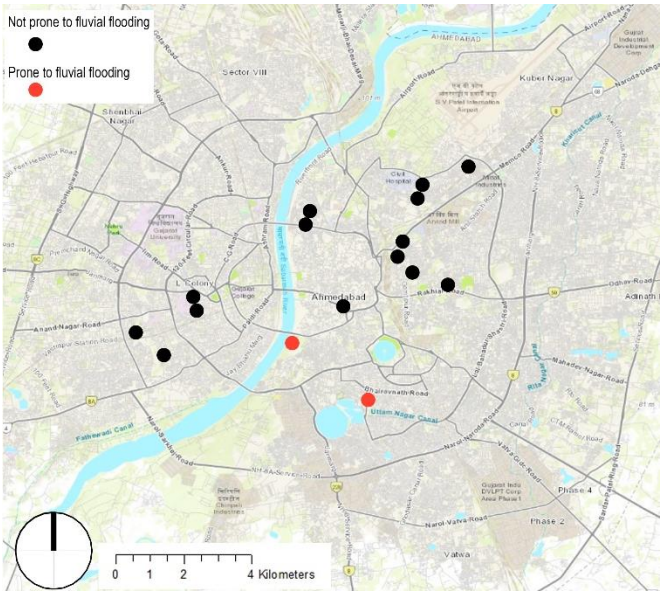


Fig.29: Study areas prone to pluvial flooding. (Source: Base map-ESRI, Locations- MTH)

(Enlarged maps in Appendix 06).

In-situ improvement: Between 1995 and 2005, AMC in partnership with local NGOs implemented the Ahmedabad Slum Networking Program. Through this partnership, services such as connection to water supply and drainage, individual toilets, slum level storm water drainage, paving of internal roads and street lighting were provided. AMC paid for 80% of the infrastructure and cost the remaining 20% was contributed by the households participating in the project. This project improved drainage and reduced inundation. (UN Habitat, 2018).

The current strategies address pluvial flooding through relocation and localized flooding through providing in-situ upgrades of drainage systems however this is insufficient if flood management is not addressed at the scale of the entire city. The city is rapidly growing and its impervious surfaces are rapidly increasing. Existing systems become obsolete if they cannot handle they cannot accommodate this. The municipality must implement ordinances to manage surface runoff at its source.

7.4 Policies to Address Water Scarcity

Currently, the only method of managing urban water scarcity is through rationing supplies. However this is insufficient since this increases uncertainty and quantity of existing supply.

It's imperative to keep in mind that water scarcity is directly dependent upon water management in the entire watershed and this requires a state wide initiative. Possible initiatives at other scales have been listed in the table below:

At Household Level
Rain water harvest
Recharge ground water for improving water supply in local bore wells
At the Community Level
Community rain water harvesting tanks
Pool resources to purchase water during severe droughts
Municipal policies
Mandatory rain water harvesting ordinance
Prioritize servicing vulnerable communities over others when rationing resources –strengthen urban governance
Promote accountability: even if supply is intermittent, provide a schedule.

Table 18: Possible recommendation at the household, community and municipal level.

7.5 Policies to Address Vector Borne Deceases

Existing vector management strategies include:

- Indoor Residual Spraying (IRS) in selected high risk areas
- Outdoor spraying of insecticide for both larval and adult control measures.
- Distribution of mosquito nets
- Using larvicolous fish to reduce larvae
- Community awareness campaigns
- Breeding site inspections and levying administrative charges for noncompliance (AMC,2018)

The main challenge is the prevalence of mosquito breeding sites. Such pockets of water are abundantly found across the city. The figure below illustrates common breeding locations within slums

Fig.30: Mosquito larvae breeding in various habitats: (a) barrel, (b) tire, (c) mud pot, (d) plastic bucket, (e) dustbin, (f) plastic drum, (g) plastic bowel, (h) jerrican, (i) ditch, (j) containers in house, (k) bucket, and (l) polythene sheet. (Getachewet al., 2015)

Additional recommendations include education on preventive measures such as the necessity to keep surroundings clean and free of stagnant water and access to better nutrition in times of sickness (in addition to cheaper treatment options).

8. Conclusion

The aim of this study was to assess susceptibility of slum communities to four key climate stressors 1) heat wave, 2) flooding and inundation, 3) water scarcity and 4) vector borne deceases. The study explored the context of each of these factors through a review of existing literature and assessed risk at the city and community level by measuring the relative vulnerability through a combination of remote sensing and GIS application. Typologies of settlements are identified on aerial imagery through their location and distinct urban footprint.

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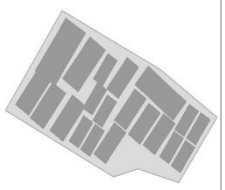
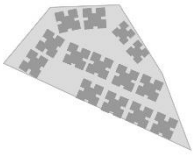
Squatter settlement	Relocated slums	*Chawl* or *Chali*	*Pol*	Hazard prone areas
				

Random clustering	Distinct and repetitive geometry	Located in the North-Eastern part of the city	Located in the historic core of the city	Located on flood prone areas

Table.19: The typical characteristics of each Typology and relative susceptibility.

The relative susceptibility of each typology in comparison to one another can be seen in the figure below. Such an analysis can help direct efforts towards causes that need it the most.

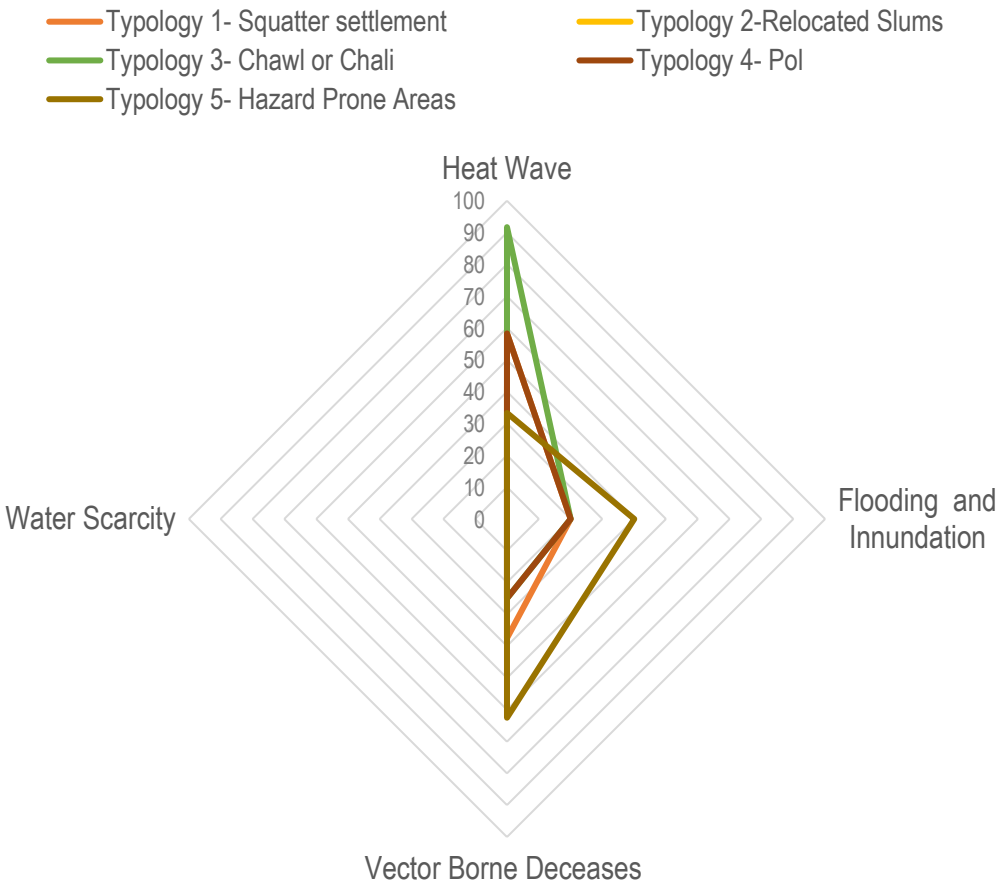


Fig. 31: relative susceptibility of each typology in comparison to one another. (Calculations in Appendix 10)

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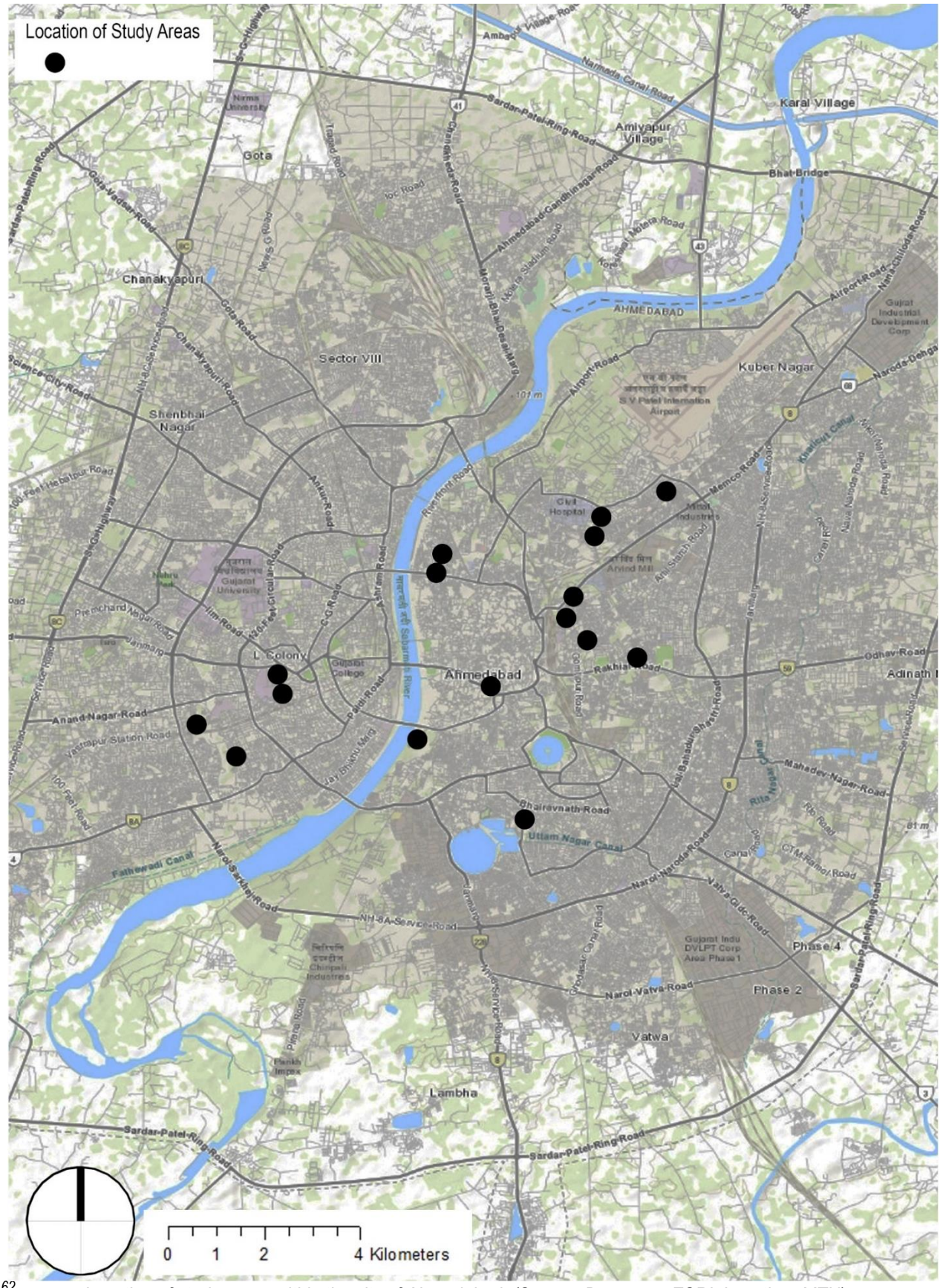
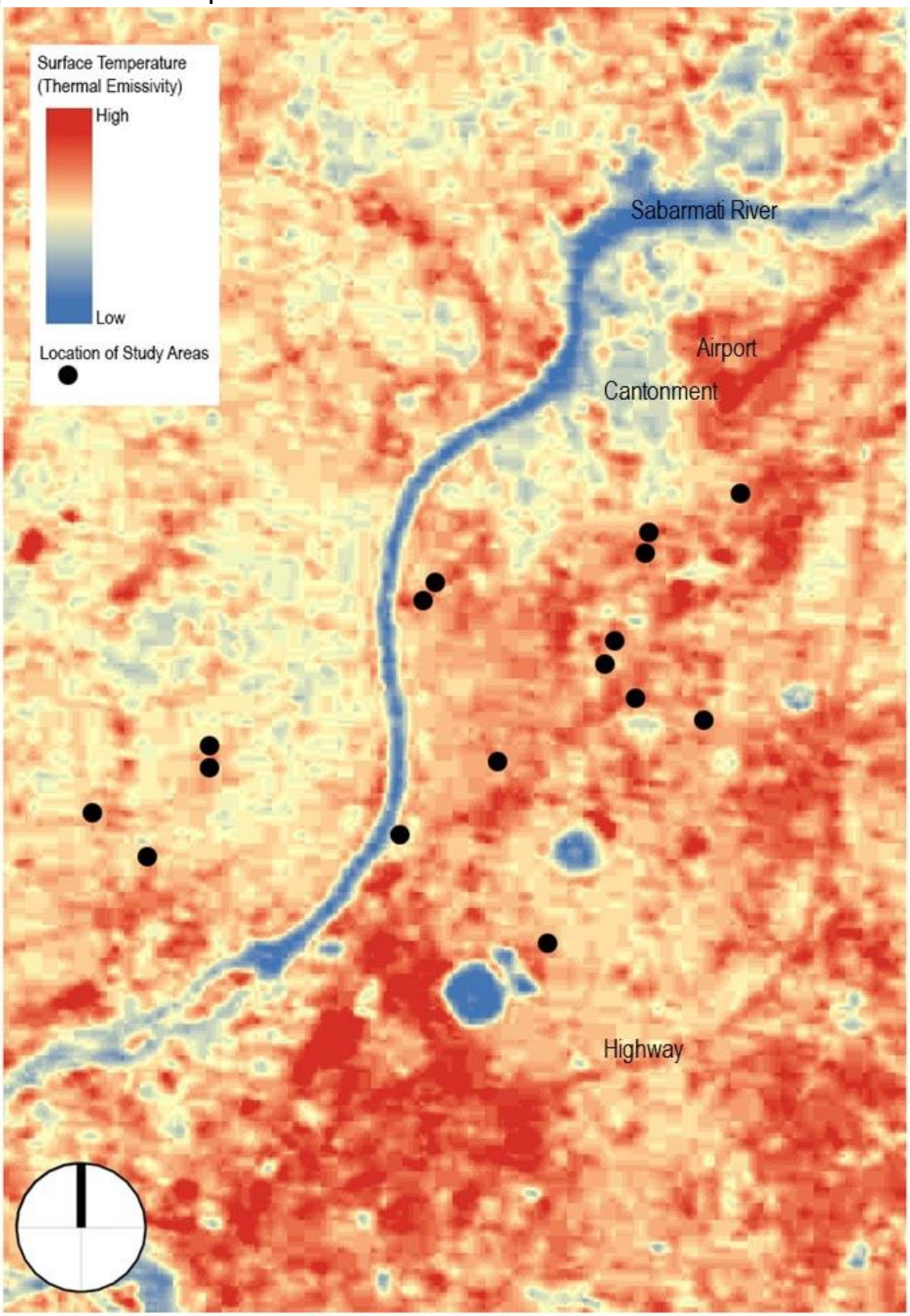
Appendix 01: Location of study areas within the city of Ahmedabad



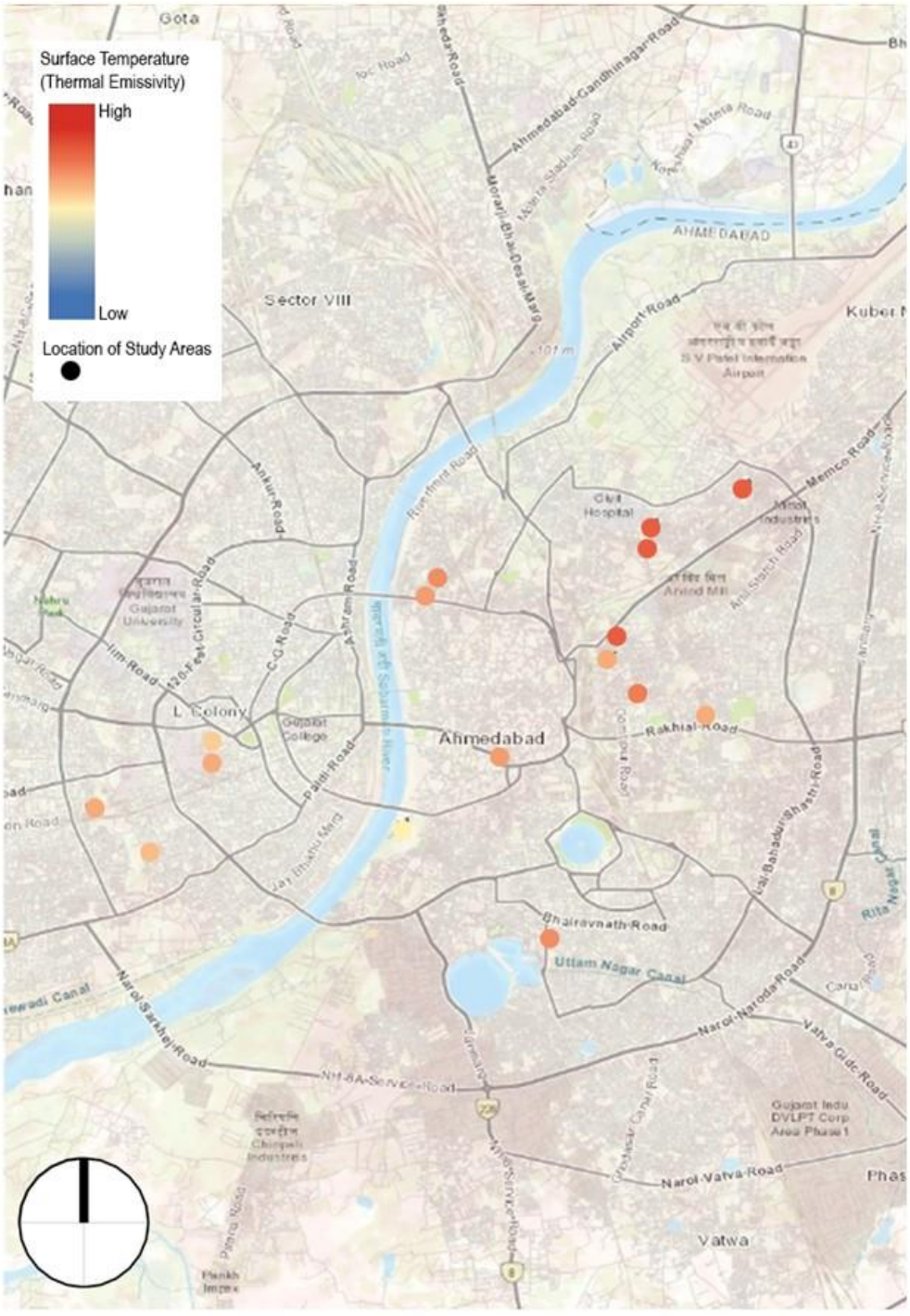
Location of study areas within the city of Ahmedabad. (Source: Base map-ESRI, Location- MTH)

Appendix 02: Surface temperature based on land cover



Surface temperature based on land cover.

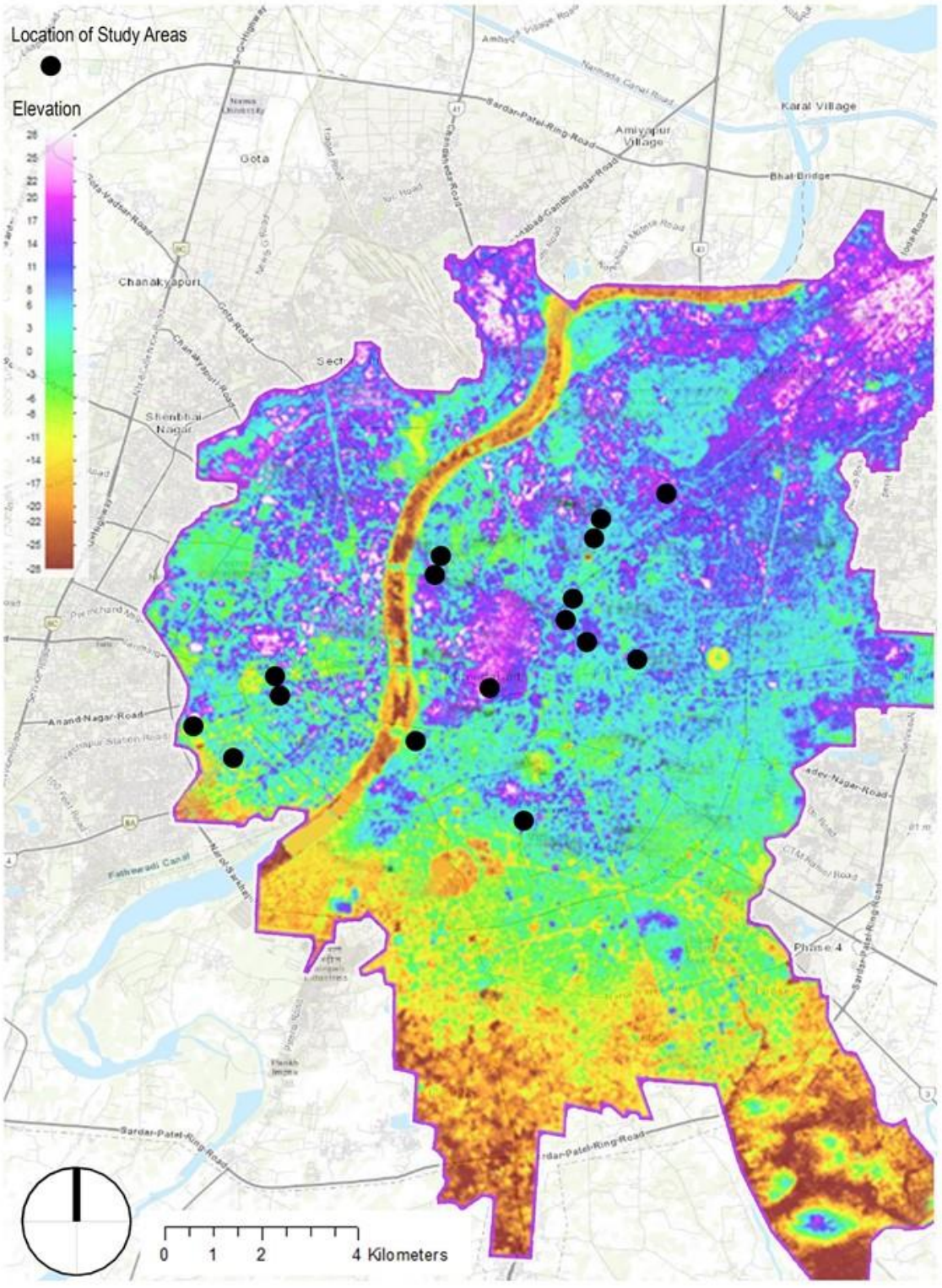
Appendix 03: Surface temperature based on land cover



Surface temperature based on land cover.

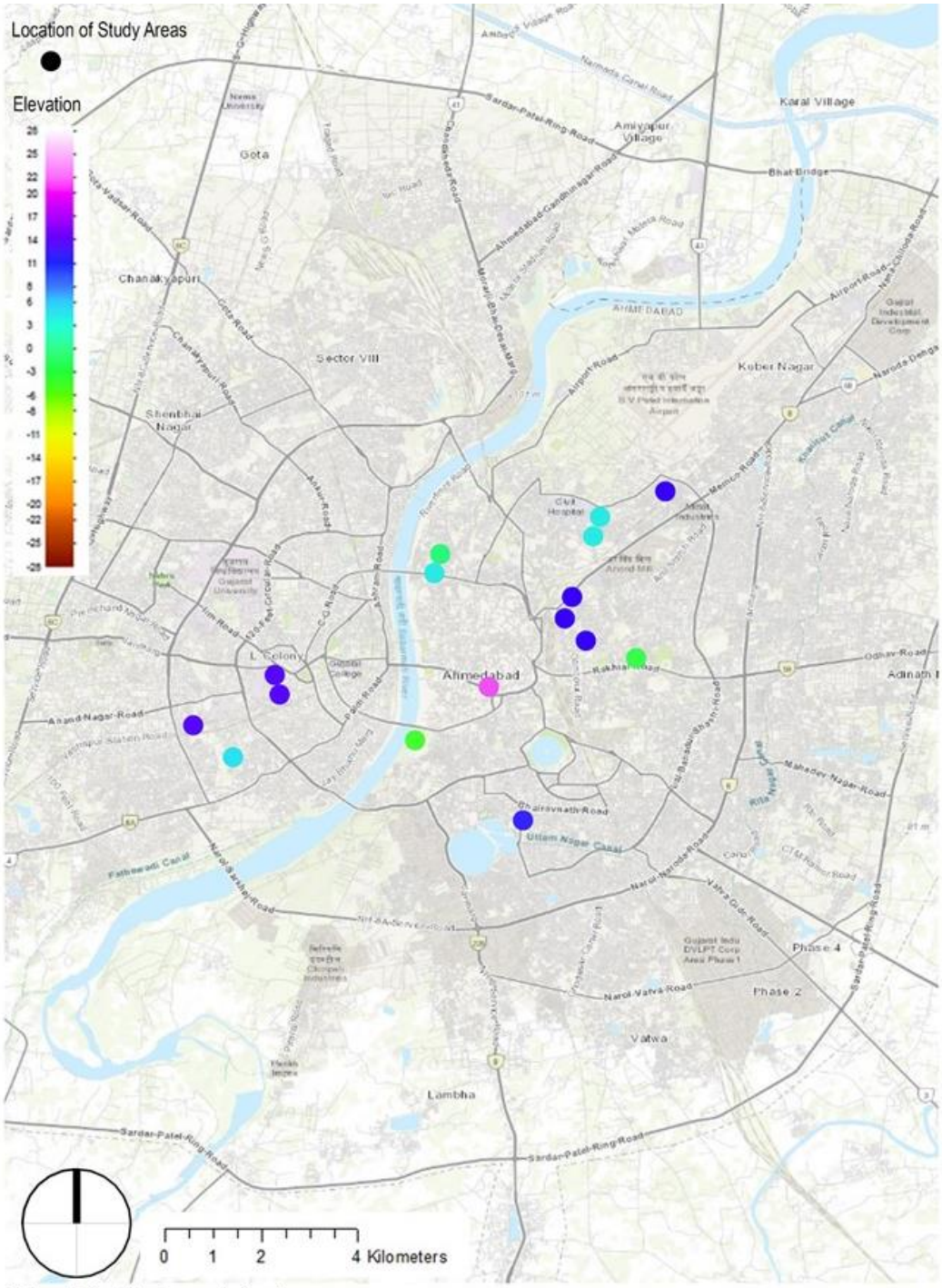
The map captures the average surface temperature (surface heat emissivity) in different part of the city. The waterbodies have the lowest daytime surface temperature, places with high vegetation and tree cover (such as Ahmedabad cantonment and university area) are relatively cooler and areas with least vegetation and high degree of paved surfaces (airport, highways) have high surface temperatures. Data was acquired from Landsat TM4-5 satellite. The image was captured on 2011-11- 14 with 30m resolution.

Appendix 04: Vulnerability of study areas to overland and localized flooding.



Vulnerability of study areas to flooding.

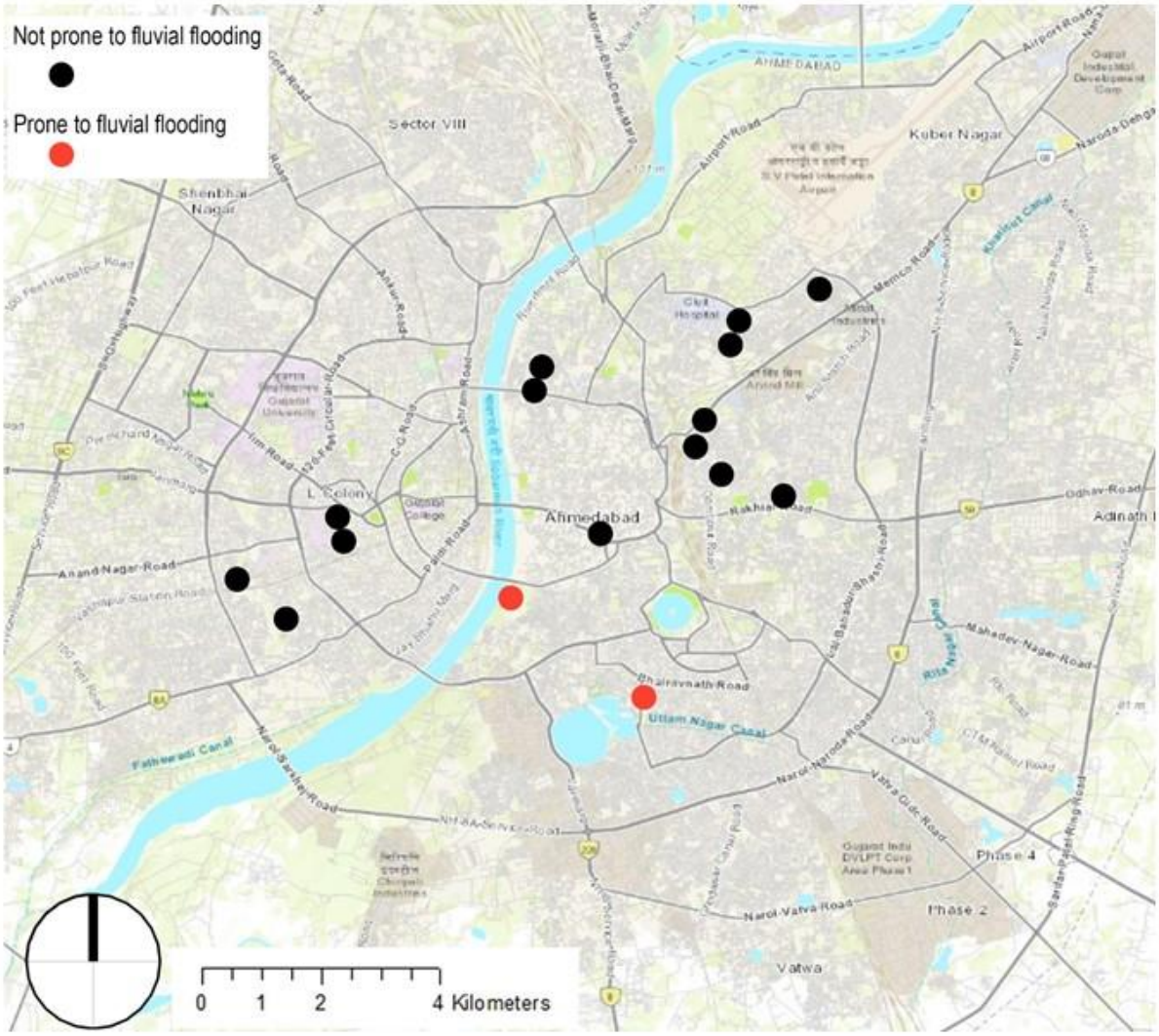
Appendix 05: Vulnerability of study areas to overland and localized flooding.



Vulnerability of study areas to flooding.

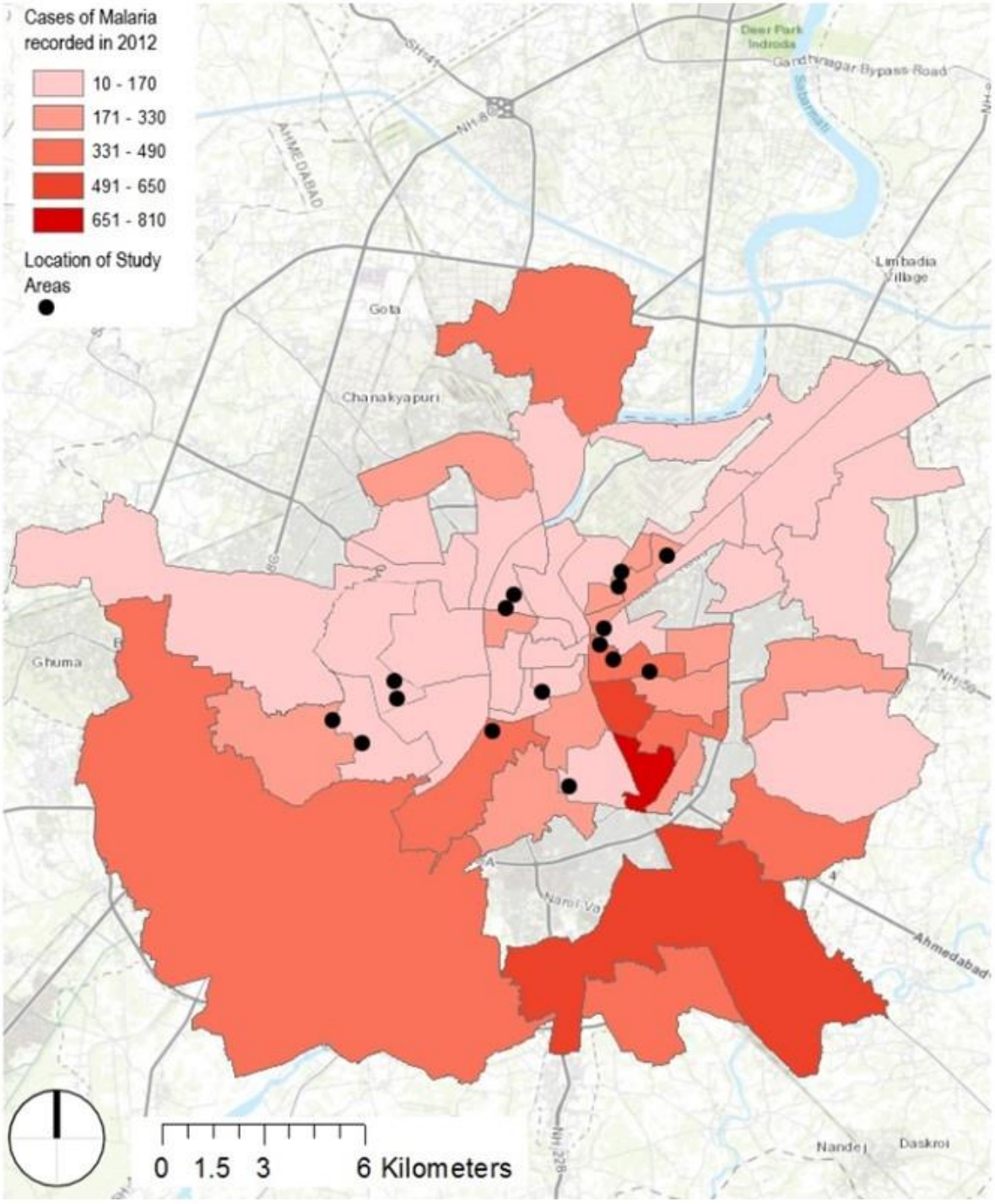
The map assesses vulnerability to localized flooding by identifying relative elevation of the settlements. By definition slums do not have adequate drainage and storm water infrastructure. Hence settlements situated in low lying areas are more likely to severely impacted by flooding. Overall, the city's topography slopes to the south. Digital Elevation Model (DEM) data was acquired from Shuttle Radar Topography Mission (SRTM) on 11 February 2000. The data resolution is 30m with absolute vertical height accuracy of less than 16m.

Appendix 06: Study areas prone to pluvial flooding



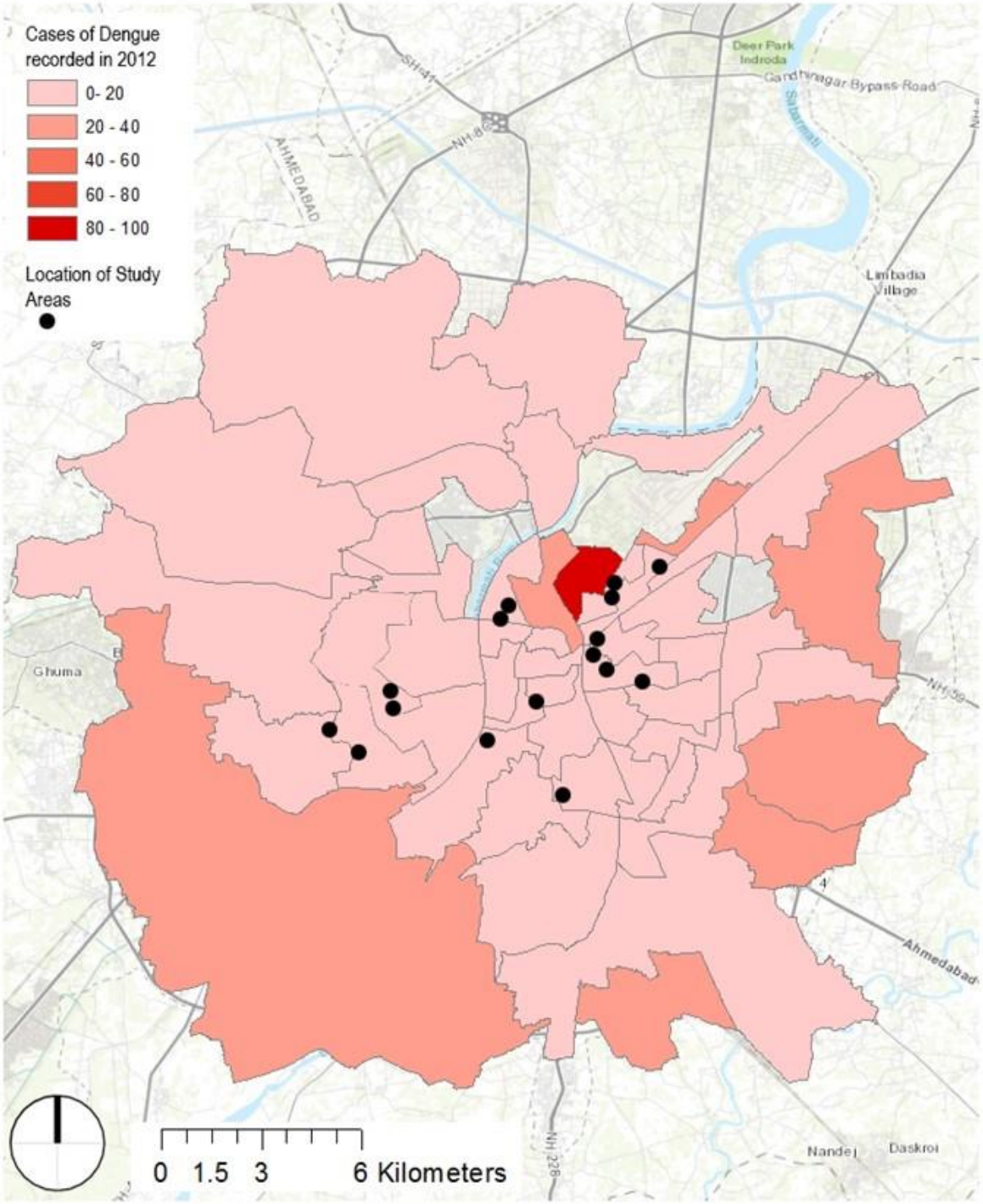
Study areas prone to fluvial flooding.

Appendix 07: Cases of malaria recorded in 2012



Cases of malaria recorded in 2012.

Appendix 08: Cases of dengue recorded in 2012



Cases of dengue recorded in 2012.

Appendix 09: Study sites

Study Sites- 16 Communities.


Sinheshwari Nagar


Jadibanagar na Chapra


B Colony (Lakshminagar)


Bala Pir No Tekra


Vivekanand Nagar


Shantinagar Bhilwas


Ravishankar Maharaj


Rajivnagar


Abhuji na Chhapra


Amdupura (Shiv Shaki Nagar)


Fakira Tank (Devi Pukaj Nagar Co.op Housing)


Himandri Mill


Madras ni Chali


Damorvali Chali


Dhal ni Pol


Baba Lavlavinagar

Appendix 10: Calculations

	Weightage	Abhuji na chhapra	Rajivnagar	Madras Ni Chali	Dhal ni Pol	Baba Lalavinagar	Source
Susceptibility to heat wave							
Exposure							
Relative surface temperature	High (3) Medium (2) Low (1)	2	2	3	3	1	Aerial imagery
North -south orientation of settlement	No (1) Yes (0)	1	1	1	0	1	Aerial imagery
Percentage of houses with tin roof	High (3) Medium (2) Low (1) None (0)	0	1	3	0	1	(MHT, PAS)
Coping Strategies							
Access to shaded and open spaces	No (1) Yes (0)	0	0	0	1	0	Aerial imagery
Access to electricity	No (1) Yes (0)	0	0	1	0	0	(MHT, PAS)
Percentage of green spaces within community	Low (3) Medium (2) High (1)	2	3	3	3	1	Aerial imagery
		5	7	11	7	4	
	%	41.7	58.3	91.7	58.3	33.3	
Flooding and inundation							
Exposure							
Situated in low lying areas	Yes (1) No (0)	0	1	0	0	1	Aerial imagery
Situated near waterbodies	Yes (1) No (0)	0	0	0	0	1	Aerial imagery
Coping Strategies							
Presence of underground drainage system	No (1) Yes (0)	0	0	0	0	0	(MHT, PAS)
Presence of multiple story	No (1) Yes (0)	0	0	0	0	0	Aerial imagery
Proximity to pervious surfaces (infiltration)	No (1) Yes (0)	0	0	1	1	0	Aerial imagery
		0	1	1	1	2	
	%	0	20	20	20	40	

Vector borne decease							
Exposure							
Cases of Malaria recorded in the ward in 2012	High (3) Medium (2) Low (1)	1	2	1	1	2	(UMC)
Cases of Dengue recorded in the ward in 2012	High (3) Medium (2) Low (1)	1	1	1	1	1	(UMC)
Proximity to open water	Yes (1) No (0)	0	0	0	0	1	Aerial imagery
Presence of dense vegetation around the community	Yes (1) No (0)	1	0	0	0	1	Aerial imagery
		3	3	2	2	5	
	%	37.5	37.5	25	25	62.5	
Water Scarcity							
Coping Strategies							
Access to municipal water supply	No (1) Yes (0)	0	0	0	0	0	(MHT, PAS)
	%	0	0	0	0	0	